JULY 1958

THE WELDING JOURNAL

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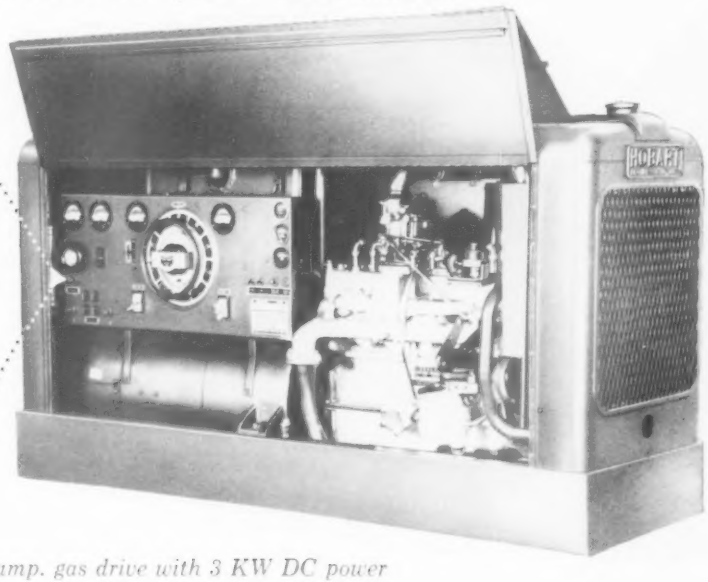

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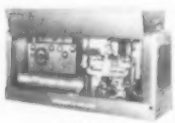

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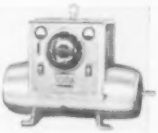

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Technical Welding Data:
(USS) "T-1" Constructional Alloy Steel

3. Effect of welding on notch toughness

THE EFFECT OF WELDING on the notch toughness of steel is normally determined by Kinzel-type notch-bend tests on welded and unwelded plate in the quenched and tempered condition. Details of the welded plate specimen are shown in Figure 1. The unwelded specimens are identical to the welded, except for the omission of the weld. The plate temperature prior to welding is 70° F., and after welding, the specimens are aged at 50-80° F. for a minimum of three weeks. The specimens in sets of about 25 are then bent at various temperatures with the weld bead in tension as shown in Figure 1. In general, three specimens are tested at each temperature.

INFORMATION DETERMINED FOR EACH SPECIMEN TESTED

1. Total (maximum) angle of bend and angle of bend at maximum load. Obtained from deflection-angle curve.
2. Fracture mode expressed as per cent shear. Obtained by observation of fracture.

The data obtained are plotted on the basis of testing temperature, and envelopes are drawn around the plotted points to indicate the amount of scatter. The curves for ½"-thick USS "T-1" Steel plate welded with E-12015 electrodes are shown in Figure 2. The data are for specimens taken longitudinal to the final rolling direction of the plate.

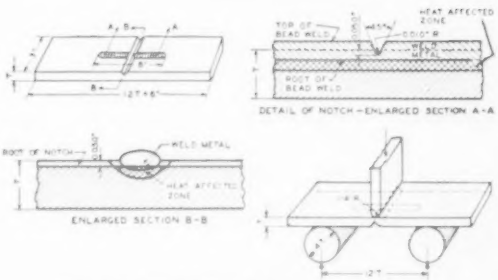
TO DETERMINE DUCTILITY-TRANSITION TEMPERATURES, the middle of the temperature range in which the total angle of bend drops rapidly to a low value is chosen. This is the temperature at the middle of the "scatter band" in the angle of bend curve in Figure 2.

THE FRACTURE-APPEARANCE-TRANSITION TEMPERATURE is also determined. As used here it is the temperature at which 50% of the fracture occurs in the shear mode, i.e., 50% of the fracture is fibrous. Typical curves are shown in Figure 2.

The results of notch-toughness studies on ½"-thick plate are given in the Summary, at right. The Summary includes data for Regular Quality plate as well as data for Firebox Quality plate.

It should always be borne in mind that at the present time there is no absolute correlation between transition temperature as obtained experimentally with the various types of specimen and service performances. *Results obtained from the same types of tests on different steels should be very useful in establishing the relative merit of the steels.*

REMEMBER THIS: No other alloy steel offers the combination of properties that "T-1" Steel possesses. Here, in just one steel, you get very high yield strength (100,000 psi minimum), extraordinary toughness, great resistance to impact abrasion, and good high temperature strength. These let you reduce the size of highly stressed parts . . . save weight, reduce the amount of welding required and cut your costs.



WELDING CONDITIONS: electrode diameter 3/16"; current (amps.) 180; voltage 27; speed of travel (in./min.) 6.0; heat input (watt sec./in.) 48,000.

Fig. 1. Details of Kinzel-type notch-bend specimen and of testing jig.

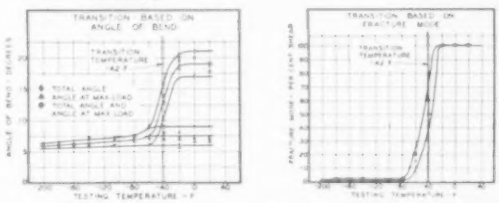

TRANSITION BASED ON ANGLE OF BEND
TRANSITION TEMPERATURE
TOTAL ANGLE
ANGLE AT MAX. LOAD
TOTAL ANGLE AND ANGLE AT MAX. LOAD
TESTING TEMPERATURE - °F
TRANSITION BASED ON FRACTURE MODE
TRANSITION TEMPERATURE
TESTING TEMPERATURE - °F

Fig. 2. Measurements and transition-temperature selection criteria in Kinzel-type notch-bend test.

Summary of notch-toughness test data on ½" USS "T-1" Steel plate (heat No. 74L236)

Test	Type of Plate	Specimen Orientation	Specimen Condition	Ductility-Transition temp., °F.*	Fracture-Appearance-Transition temp., °F.**
Kinzel notch-bend	Firebox Quality	Long.	Unwelded	minus 68	minus 67
Kinzel notch-bend	Firebox Quality	Trans.	Unwelded	minus 62	minus 59
Kinzel notch-bend	Regular Quality	Long.	Unwelded	minus 130	minus 128
Kinzel notch-bend	Regular Quality	Trans.	Unwelded	minus 91	minus 91
Kinzel notch-bend	Firebox Quality	Long.	Welded†	minus 42	minus 42
Kinzel notch-bend	Firebox Quality	Trans.	Welded†	minus 50	minus 47
Kinzel notch-bend	Regular Quality	Long.	Welded†	minus 92	minus 89
Kinzel notch-bend	Regular Quality	Trans.	Welded†	minus 112	minus 112
Kinzel notch-bend	Firebox Quality	Long.	Welded and stress-relieved‡	minus 30	minus 27

* *Taken at middle of bend*
** *Selected at 50% shear*
† *E12015 electrodes*
‡ *E9015 electrodes; Stress-relieved at 1100° F. for 1 hr.*

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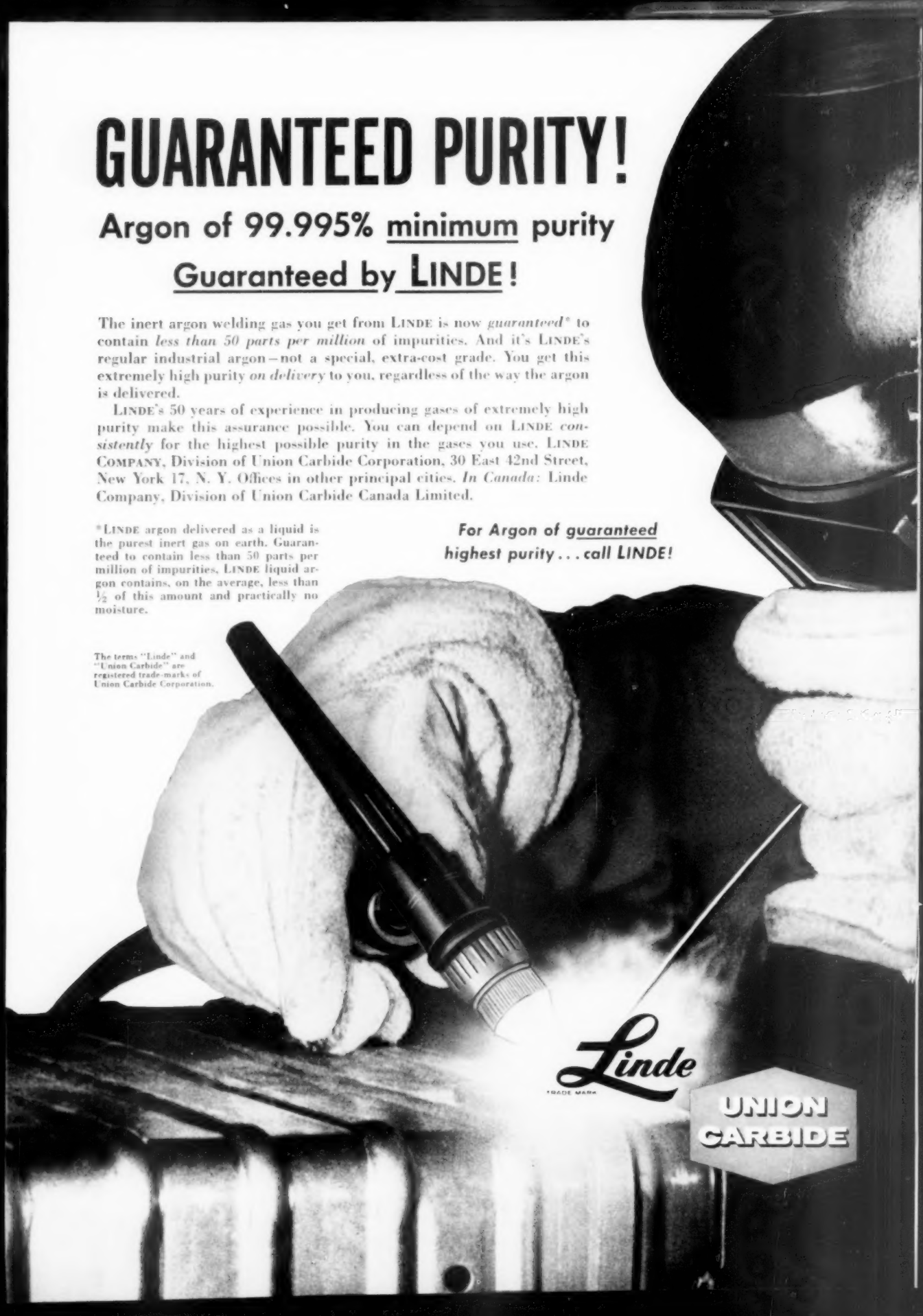

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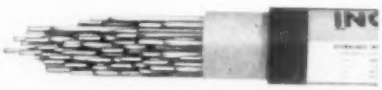

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THE
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EDITORIAL

RESISTANCE-WELDING RESEARCH

An improvement in the reliability and quality of resistance welds presents a real basic research challenge to the universities and industrial laboratories of our country.

Considering only the resistance spot-welding process, a wide range of fundamental metallurgical, electrical and mechanical phenomena is involved. There are many fundamental properties that are not well defined by existing knowledge. Although limited work has been done to develop the needed data, there are serious deficiencies in our basic knowledge of the fundamentals that affect the completion of a satisfactory resistance spot weld.

Development of a satisfactory nondestructive test for resistance welds would eliminate the greatest single barrier to more extensive use of the process. The failure of our research laboratories to provide such a tool is resulting in added costs throughout our country's defense and commercial production operations. Much of this cost results from the necessity of elaborate sampling procedures utilizing specimens or simulated structures which must be subjected to destructive tests in order to obtain some measure of control of critical spot-welding operations. There are many applications where the lack of nondestructive test methods has either slowed down or completely prevented acceptance of resistance-welded structures.

An industry committee recently placed high priority on the development of a sensing control that would automatically compensate for the variables that exist in spot welding and thus produce satisfactory welds. The variables which were to be considered included current, time, force, material in the secondary loop and many others. This illustrates the complexity of the problem and the urgent need for additional knowledge and development work.

These many problems have been mentioned so that none of us will forget the many unanswered questions that are inherent in even our simplest resistance-welding operations. This should and must lead us to the support of research programs that will promote improved quality and wider acceptance of the resistance-welding processes.

John F. Randall
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INERT-GAS TUNGSTEN-ARC WELDING OF TITANIUM FOR NUCLEAR AND CHEMICAL INDUSTRIES

Welding program develops titanium welding procedures and the corresponding specifications for making titanium welds, either on the bench or in the field

BY G. M. ADAMSON AND W. J. LEONARD

ABSTRACT. A process has been developed and is described by which unalloyed titanium may be field welded using only conventional inert-gas tungsten-arc equipment. The process is applicable to the high-quality individual welds required in field welding for the chemical industry rather than to high-speed repetitive production welds.

Introduction

The Homogeneous Reactor Project is a power-reactor project in which an aqueous solution of uranyl sulfate at about 600° F and 2000 psi is used as the fuel. This solution replaces the complicated and expensively fabricated solid-fuel elements which are used in most reactors. The use of a circulating fuel places these reactors in the category of chemical plants and one of the major problems, as in many chemical plants, is corrosion, either from the solution itself or from stress corrosion from chloride impurities. The present structural material is Type 347 stainless steel and, while this material is suitable for the present small, short-lived experimental reactors, it is of doubtful use for the contemplated large-scale reactors. Many of the corrosion problems could be eliminated, or at least alleviated, if titanium were used as a structural material. One of the major problems preventing the use of titanium has been the lack of proved welding procedures suitable for field welding of a chemical plant.

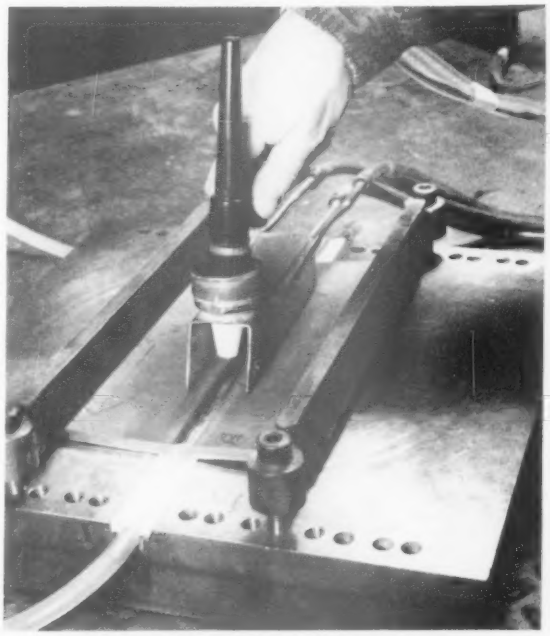


Fig. 1 Metallic trailers attached to welding torch

While titanium is a common material in the aircraft industry, it is just beginning to be accepted in the field of industrial chemistry. Its use has been deterred by the combination of high initial cost, lack of fabricated parts and lack of welding procedures. The development of such procedures was the purpose of the work to be discussed in this paper.

In its more likely applications in the chemical industry, titanium must be considered as being a competitor of stainless steels and high-nickel alloys. To be competitive, it will be necessary to develop titanium-welding methods that are comparable to those available for the other alloys. Unfortunately, titanium is a very active

G. M. Adamson and W. J. Leonard are associated with the Oak Ridge National Laboratory.

Paper presented at the AWS 1958 Annual Spring Meeting held in St. Louis, Mo., April 14-18.

metal, similar to zirconium, molybdenum and uranium and reacts readily, at elevated temperatures, with several of the gases in air. The likelihood of such reactions during welding is further increased by titanium's high melting point and low thermal diffusivity. These reactions are detrimental to both the mechanical and physical properties of the metal. While welding procedures for some titanium alloys have been developed by the aircraft industry, they are usually developed for a single application and often make use of dry boxes or other special protective devices. In general, they are not suitable for field welding of pipe or chemical vessels.

The purpose of this welding program was to develop titanium-welding procedures and the corresponding specifications for making titanium welds either on the bench or in the field. The major effort was placed on using essentially conventional inert-gas tungsten-arc welding equipment, while smaller backing programs included welding in inert-atmosphere boxes and using portable protective shields.

While, as with most other metals, titanium must be free from dirt or scale to avoid contamination, the most common source of contamination is from the reaction of hot or molten metal with air. Titanium is capable of reacting with nitrogen, oxygen, hydrogen, water vapor or carbon dioxide. When present in titanium, nitrogen and oxygen are both alpha stabilizers and thereby raise the alpha to beta transformation temperature. They increase the tensile and yield strength while markedly reducing ductility. Both gases are soluble at elevated temperatures, with the solubilities decreasing rapidly with lowering temperatures. Hydrogen is a beta stabilizer and lowers the alpha to beta transformation tem-

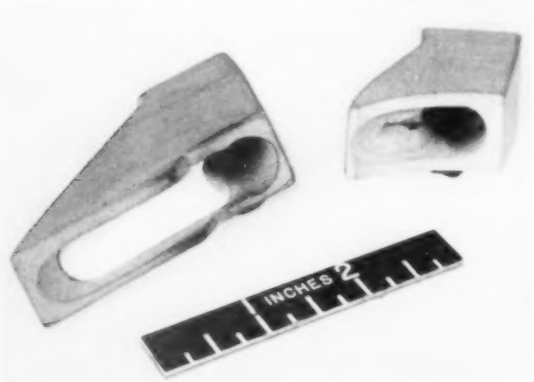


Fig. 2 Combined welding-torch gas cup and trailer

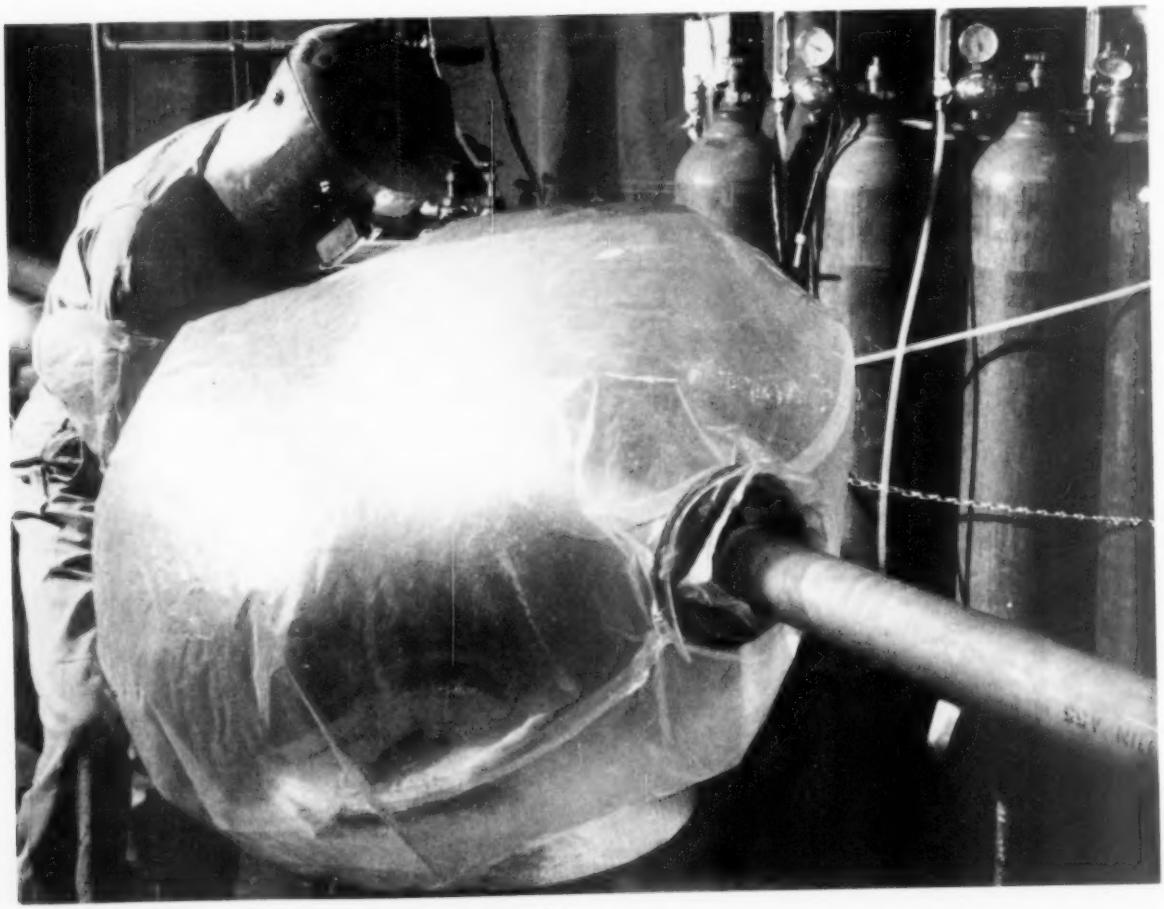


Fig. 3 Plastic bag used for all-position titanium pipe weld

Table 1—Mechanical Properties of Stock

Material*	Form	Tensile strength, psi	Yield strength, psi, 0.2%	Elongation in 2 in., %	Bend radius	Others
A-40	0.062-in. plate	51,400	39,600	41.7	2 x thickness	
A-40	0.250-in. plate	47,800	33,500	39.2	2 x thickness	
A-55	0.250-in. plate	84,520	69,530	27	2 x thickness 105°	
A-40	¼-in. schedule 80 pipe	75,600	52,100	31		
A-55	2½-in. schedule 40 pipe	80,600	58,200	28		
A-40	0.062 and 0.092 in. wire					
A-40(a)	0.062 in. wire	71,000	49,000	42.5		51% reduction area
A-40(a)	0.092 in. wire	74,100	52,000	33		52% reduction area
A-40(a)	0.125 in. wire	72,000	48,100	40.5		56.5% reduction area
A-40(b)	0.092 in. wire	69,800	51,100	39		
A-55	0.062 in. wire	73,500	52,500	37.5		54% reduction area
A-70	0.062-in. wire	99,300	70,900	28		
A-70	0.092-in. wire	113,200	80,200	27		

* Stock from all vendors reduced to a standard nomenclature for facility and clarity.

Table 2—Chemical Certification of Stock Used

Material*	Form	C	N_2	H_2	Others
A-40	0.062- and 0.250-in. plate 0.062- and 0.095-in. wire	<0.1%	<0.010%	55 ppm	-
A-40	¼-in. schedule 80 pipe	0.016%	0.015%	62 ppm	0.12% Fe
A-55	2½-in. schedule 40 pipe	0.033%	0.011%		0.26% Al
A-55	0.250-in. plate	0.1%	0.014%	120 ppm	
A-40(a)	0.062 in. 0.092-in. wire 0.125 in.	0.027% 0.027% 0.027%	0.020% 0.020% 0.020%	40 ppm 40 ppm 40 ppm	0.046% Fe 0.046% Fe 0.046% Fe
A-40(b)	0.092-in. wire	0.02%	0.007%	99 ppm	0.18% Fe
A-55	0.062-in. wire	0.018%	0.026%	50 ppm	0.092% Fe
A-70	0.062-in. wire 0.092-in. wire	0.125% 0.125%	0.012% 0.012%		

* Stock from all vendors reduced to a standard nomenclature for facility and clarity.

perature. If present in moderate quantities, it leads to embrittlement.

Three general classes of titanium alloys are now being produced commercially. The largest tonnage is in the high-strength, two-phase, alpha-beta alloys. These alloys are considered as being essentially unweldable and are often unstable at elevated temperatures. For these reasons, they have not been included in this welding study. The second group, just coming into wide usage, are the alpha alloys. At present, only one all-alpha alloy composition, A-110AT,* is available commercially and considered to be a moderate-strength weldable alloy. Welding techniques are being developed for this alloy, a discussion of which is outside the scope of this paper. The third group of alloys is the so-called unalloyed titanium. This group covers a wide range consisting of high-purity titanium alloyed with varying small quantities of oxygen, nitrogen and carbon. These alloys are readily available commercially and are the only ones presently fabricated into pipe and tubing. This paper is concerned with these alloys, primarily those at the higher-purity, or lower-yield strength end of the series.

Material and Equipment

Titanium was used in a variety of sizes and compositions in this work. These data have been tabulated in Tables 1 and 2.

Initial titanium welds were made using procedures approved for austenitic stainless steels, but carried out inside a dry box. Such boxes are gas-tight vessels in which the air is replaced by either helium or argon. The welder can observe his work through windows and is able to handle his equipment through large gas-tight gloves. Two types of dry boxes were used: a conventional box in which the air was removed with vacuum pumps and replaced with an inert gas, and a simpler box with the sides constructed of neoprene. The air was replaced by repeatedly collapsing the box and then inflating it with an inert gas. While both of these boxes provided positive gas protection, it is obvious that they have serious size limitations, are slow and awkward to use and are not very portable for field use. In order to provide a portable dry box, three special devices were used. In the first case, a small metal box, or trailing shield, with a shape contoured to the surface to be welded, was attached to the torch to move with it. The trailing shield maintains an inert atmosphere over the weld and adjacent area, both while it is being made and during the initial stages of cooling. Such a trailer is shown in Fig. 1. These trailers were adapted from a procedure previously used for the welding of a large zirconium vessel.[3] A second trailer-type shield was

* Composition 5 Al-2.5 Sn, balance titanium.

Table 3—Recommended Conditions for Dry-Box Welding

Joint	Base-metal thickness	Root gap, in.	Filler diam., in.	Current range, amp DCSP: Tacks	Root pass	Filler passes	Voltage	Torch gas flow, cfh, A or He
1	0.020	0		15-25	20-30		8-15	8-15
1	0.031	0		15-25	20-30		8-15	8-15
1	0.047	1/32		20-30	25-40		8-15	8-15
1	0.062	1/16	1/16	30-40	35-50		8-15	8-15
2,4	0.063-0.250	1/32	1/16	25-35	40-60	60-90	9-16	8-15
3,5	0.251-0.500	0	3/32	30-40	25-45	(2)25-45 60-90	9-16	8-15
	0.501-0.750	0	3/32	30-40	35-60	(2)35-60 60-90	9-16	8-15

Table 4—Recommended Limits for Variables in Tungsten-arc Air Welding of Titanium

Joint	Base-metal thickness	Root gap, in.	Filler diam., in.	Current range, amp DCSP: Tacks	Root pass	Filler passes	Volts	Gas flow, cfh, torch trailer backing: A	A	He
1	0.020	0		15-25	20-30		9-14	8-13	20-30	30-60
1	0.031	1/32		15-25	20-30		9-14	8-13	20-30	30-60
1	0.047	1/16		20-30	25-45		9-14	8-13	20-30	30-60
1	0.062	1/32	1/16	30-45	30-50		10-15	10-15	20-30	30-60
2,4	0.063-0.250	1/32	1/16	40-55	45-65	60-90	10-16	10-18	20-30	30-60
3,5	0.251-0.500	1/16	1/16	40-55	35-50	(2)35-50 60-90	10-16	10-18	20-30	30-60
	0.501-0.750	1/16	1/16	40-55	40-60	(2)40-60 60-90	10-16	10-18	20-30	30-60

made by incorporating the trailer into the protective gas cup of the welding torch. Such a cup would no longer have a circular cross section but would have a rectangular addition on the trailing edge as is shown in Fig. 2. The third portable dry box was achieved by the use of an inflatable plastic bag surrounding the work. These bags are firmly attached to the work and moved by means of slip rings. The welder had to control his work by means of gloves built into the bag. A typical bag is shown in Fig. 3.

Conventional inert-gas tungsten-arc-welding equipment was used for the larger part of the work in this study, the only major modification being the use of large-size ceramic gas cups 1/2 to 3/4 in. in diam. With the tungsten-arc-welding procedures, care must be used to provide adequate inert-gas coverage on the root side of every weld. This may be accomplished by purging a closed vessel or by building special devices to retain the gas under the weld. Such an operation is shown in Fig. 4.

Discussion

One difficulty in the development of titanium-welding procedures is the lack of suitable testing methods. In this particular program, wide use was made of conventional weld-inspection methods, such as visual inspection, radiography and liquid penetrants. However, none of these determined the occurrence of contamination. Welds acceptable by other methods were, therefore, further tested either by a guided-bend test or, more commonly, sectioned and examined metallographically. Microhardness measurements from specimens were shown to be a simple and satisfactory method for determining contamination. While considerable variation may be noted in individual values, averages

Fig. 4 Inert-gas shielding of root during tungsten-arc air welding

for a weld are reproducible. If considerable contamination has occurred, a change in microstructure may be noted. Raising of the alpha to beta transformation will permit the growth of coarse platelets during cooling from the welding temperature. Photomicrographs of a

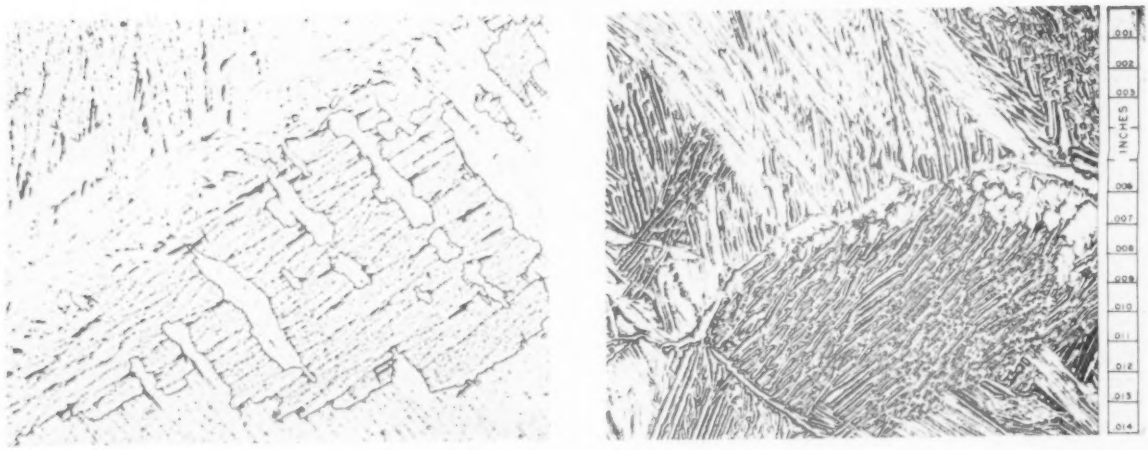


Fig. 5 Comparison of normal and contaminated weld-metal microstructure

normal and a heavily contaminated structure are shown in Fig. 5.

Dry-Box Welding

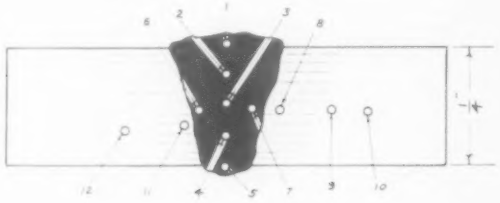
To establish quality and acceptance standards, the first welds were made in the dry boxes. With the exception of using the dry box, the techniques used were those previously qualified for Type 347 stainless steel.[3] While acceptable welds were made by these techniques, some modifications were found to be desirable. By increasing the root spacing and reducing the land, the power requirements were reduced, in turn reducing the area of high temperature. These changes permitted the use of less efficient dry boxes or reduced purging times. With the variables established within the limits tabulated in Table 3, it was possible with A-40 rod and A-55 base metal to achieve routinely hardness of less than 190 DPH (10-kg load) for plates $^3/_4$ in. and less in thickness, and less than 210 DPH for heavier welds.

Air Welding

While in dry-box welding considerable latitude exists in the control of the variables, this is no longer true in tungsten-arc air welding with its increased chances for contamination. The final recommended joint designs for tungsten-arc air welding of titanium are shown in Fig. 6 with the corresponding recommendation for limits on the variables in Table 4. In arriving at these recommendations, welding variables were studied over a wide range. Root gaps were varied from zero to $^3/_{32}$ in.; filler wire from $^1/_{32}$ to $^1/_8$ in. diam; amperages from 5 to 130 amp; and torch cups from size 4 to size 10. Gas flow in the torch was investigated over the range of 5 to 25 cfh and backing purge gas from 20 to 60 cfh. Gas-mixing equipment permitted the study of helium-argon mixtures from zero to 100% of the mixing gas. Major changes from dry-box procedure have been in the direction of maintaining low temperatures through reduced power and controlling the inter-pass temperatures. In deposition of titanium, it is important that a stringer-bead technique be employed. Weaving of the torch, which produces a bead of greater width, greatly increases the inert-gas coverage problem. Most critical variables in titanium welding are discussed in greater detail in the following sections.

Typical hardness values of welds made in both types of dry boxes and in air are tabulated in Table 5. Also

Table 5—Hardness Traverse (DPH 10-kg load) on Welds of A-40 Plate and Filler Wire



Pos.	Trailer	Compressible dry box	Permanent dry box	Air	
1	183	208	179	232	182
2	198	178	183	205	187
3	205	198	185	203	197
4	175	173	172	209	183
5	188	190	198	212	173
6	198	169	185	191	170
7	186	178	163	193	193
8	144	139	128	128	122
9	130	137	122	125	128
10	135	130	127	130	125
11	131	142	120	132	123
12	123	140		124	124
		Weld metal average			
	190	185	181	206	184

Table 6—Mechanical-Property Data from Trailer Weldment

Specimen	Tensile strength, psi	Yield strength, psi	Elongation, %	Bend (2 T radius) deg
(1)	54,400	40,200	21	180
(2)	51,300	40,200	20	180

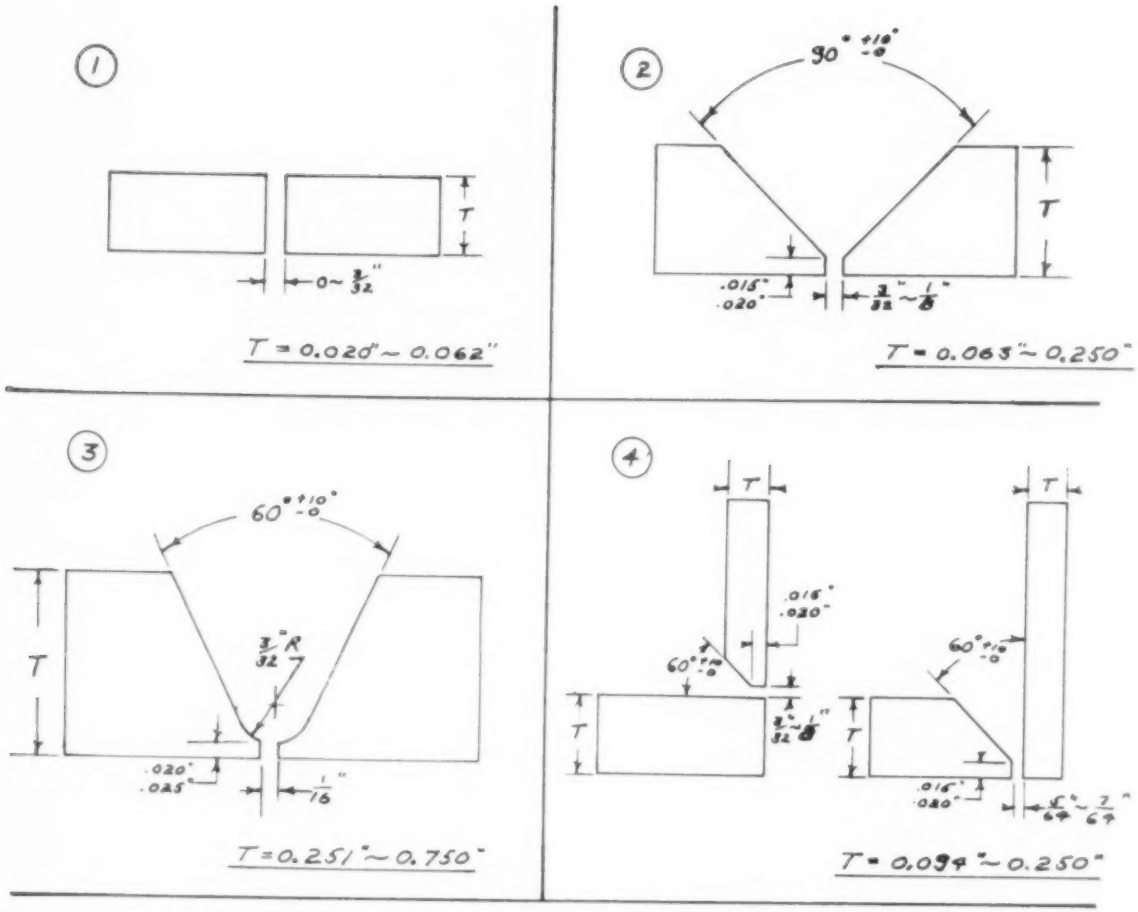


Fig. 6 Recommended joint design for tungsten-arc air welding of titanium

listed are values from a trailer weld which will be discussed later. These data show that it is possible to produce comparable welds in titanium plate using either procedure. The hardnesses indicated the trailer weld had a satisfactory contamination level and, as shown by the mechanical-property data in Table 6, this weld was satisfactory.

Another comparison of the various protective measures was obtained by making fusion welds in $^1/_{16}$-in. A-40 plates. The hardness of the original annealed plate was 135 DPH and the dry-box welds averaged 168 and 161 DPH. With a torch argon flow of 16 cfh and helium backing of 40 to 60 cfh on the root, an air weld with an average hardness of 170 DPH was obtained. Corresponding trailer welds with hardnesses of 162 and 165 DPH were also made.

A third comparison of the dry box and air welds is available from welds in A-40 pipe. This pipe was 4 in. in diam with a $^3/_{16}$-in. wall and was welded with A-40 filler wire. Again as shown by the data in Fig. 7, comparable and satisfactory welds were made by both methods. The two sets of hardness values are from different sections of the weldments. The fused base-metal zone exhibited a hardness equal to or less than deposited filler metal.

After the variables were fairly well understood, a series of tungsten-arc air welds was made similar to those required for an ASME Boiler Code qualification. Duplicate welds were made under the 2G (horizontal) and 5G (all position) requirements, using $2^1/_2$-in. Schedule 40, A55 pipe and $^3/_{32}$-in. diam A-40 filler wire.

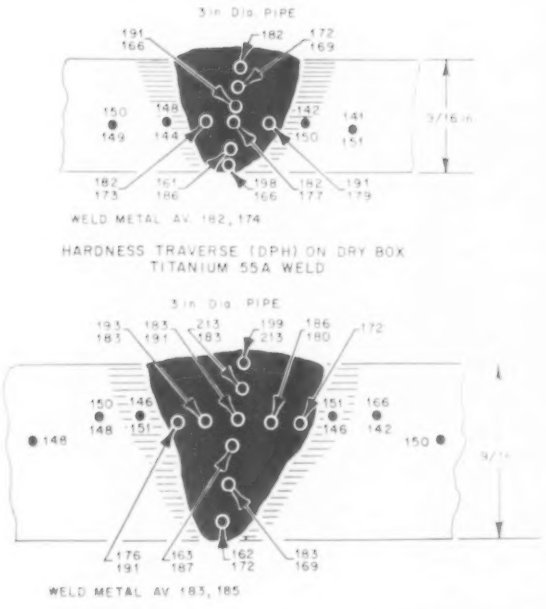
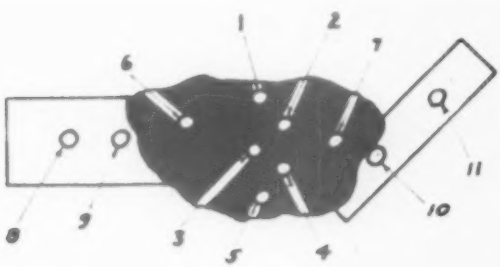

3 in. Dia. PIPE
WELD METAL AV. 182, 174
HARDNESS TRAVERSE (DPH) ON DRY BOX TITANIUM 55A WELD
3 in. Dia. PIPE
WELD METAL AV. 183, 185
HARDNESS TRAVERSE (DPH) ON AIR WELD OF TITANIUM 55A

Fig. 7 Hardness traverses for air and dry-box titanium pipe welds

Fig. 8 Typical tungsten-arc air welds in titanium pipe



POSITION	HARDNESS
1	357
2	260
3	300
4	285
5	677
6	348
7	450
8	155
9	143
10	180
11	155

Fig. 9 Hardness traverse of contaminated A-40 weld

Standard tensile and bend samples were cut from each weld and a metallographic examination of typical samples was conducted. A photograph of the completed welds is shown in Fig. 8 and mechanical-property data are tabulated in Table 7. All of these are acceptable welds and show that the results are reproducible. Hardness values of a sectioned contaminated production weld are presented in Fig. 9. These data illustrate the high degree of contamination that can occur in an improperly protected weld.

Titanium is a relatively new metal, of the hexagonal close-packed family, and sufficient basic data and experience are not available to permit a firm evaluation of its behavior by correlation of the results of various mechanical-property tests. In titanium weldments, using the same materials, no change in mechanical properties as measured by guided-bend tests was found over a hardness range of 200 to 260 DPH. However, at 250 DPH sufficient contamination had occurred that platelets in the microstructure, similar to those in Fig. 5, had become visible. In the development of these procedures, no difficulty was encountered in maintaining the hardness tolerances previously mentioned; however, with material, equipment or personnel changes, this may become more difficult. It appears that welds with average hardness values as high as 240 DPH would have acceptable mechanical properties.

As the air-welding work proceeded, it soon became obvious that, contrary to statements in the literature, a dark color on a weld was not necessarily indicative of poor quality. The most serious contamination is that which takes place at high temperatures where the diffusion rates are rapid. At such temperatures, the gaseous contaminators are soluble and can contaminate

Table 7—Mechanical-Property Data from Qualification Welds

Specimen	Tensile strength, psi	Yield strength, psi	Elongation in 1 in., %	Bend 2" x T radius, deg	Average hardness, DPH 10-kg load
1	83,619	62,190	6*	180	209
2	84,824	58,823	15	180	206
3	83,106	57,567	23	180	190
4	83,642	58,412	21	180	192
5	81,262	55,210	18	180	225
6	81,411	59,764	21	180	221
7	81,737	59,104	20	180	217
8	80,139	58,965	†	180	248

* Broke in base metal outside weld.
† Indistinct gage length not determined.

while leaving only very thin surface layers. The heavier dark films are formed during cooling and represent only superficial contamination. However, the color of a film is an indication of the adequacy of the protection during cooling and thereby an indirect indication of conditions during welding.

In the collapsible dry box, the welds were a bright silver immediately behind the torch but gradually changed to a dark gold and then blue color. In air welding the blue color was formed immediately. Welds with surface coloration varying from golden to dark blue, due only to thin surface films in the range of interference colors, have been found to be acceptable. A rainbow film indicates some contamination and should be considered questionable, while welds with films varying from a rainbow color with a translucent white tinge to dull translucent silver, are usually rejectable. The latter film is similar in appearance to those on a normal stainless-steel weld. In a $^1/_8$-in. sheet of A-40 titanium, hardnesses of single-pass welds under these films were 165 to 190 DPH for the acceptable ones and greater than 200 for the rejectable ones. Comparable colors and hardnesses were found if contamination resulted from either improper root or face protection.

While a dark-oxide layer formed during cooling and may be superficial and not harmful in a single-pass weld, it must be removed after every pass in a multi-pass weld. If such a layer is not removed, it will be dissolved on reheating and cause serious contamination. As the film becomes more tenacious, if the weld metal is permitted to cool to room temperature, prompt wire brushing is recommended for removal of such layers.

Inert-Gas Protection

Since the major difference between stainless-steel and titanium welding is the contamination of the latter from gaseous impurities, considerable effort was spent examining the inert gases and determining the most efficient handling procedures.

The lower limit of gas flow for the torch gas was established by the oxidation of the tungsten electrode rather than by protection from contamination. Even using the largest gas cup, no difficulty from contamination of the titanium was noted with argon flows as low as 8 cfh, but as in welding other metals, difficulty was encountered because of oxidation of the tungsten. The effect of turbulence in the gas curtain was determined by a series of welded plates made with gas flows of 16, 20 and 24 cfh, which yielded welds with hardnesses of 167, 188 and 193 DPH, respectively. The face colors of these welds varied from blue to rainbow with translucent white, as predicted above, while the roots which had been adequately protected were all bright silver.

Protection of the root with adequate backing gas is as critical as face protection, but it is more difficult to control and to specify what is adequate protection. The commonest source of contamination on the root is insufficient inert-gas flow for complete displacement of the air prior to welding. A minimum of six volumes of argon, or eight of helium, is necessary in easily purged vessels and pipe. These quantities must be increased for backing devices that are not as easily purged.

Where an inert gas is selected only for shielding, such as with the trailer or bag, argon is preferred. Because of higher density, argon settles down over the work with a minimum of turbulence, rather than floating away from it. However, in using the tungsten-arc air-welding procedures the gas from the torch cup not only provides the protection for the face of the weld but must also protect the tungsten and stabilize the arc as in normal inert-gas tungsten-arc welding. Helium possesses more desirable arc-voltage characteristics than does argon.[3] The relative advantages must therefore be weighed in considering each welding application. With the field welds encountered in most chemical applications, the contamination problem is the more serious of the two and, therefore, argon is recommended as the torch gas. Under special conditions where, because of geometry or location, protection is easier or more certain and contamination is, therefore, not as likely, it would be desirable to use mixtures of the two gases.

A word of caution on the purity of inert gas for use in titanium welding should be given. A gas which is of suitable quality for commercial tungsten-arc welding of austenitic stainless steel may result in serious welding

Table 8—Variation in Microhardness with Composition of Titanium Filler Metal and Pipe (DPH 10-kg Load)

Filler-wire type	*Base-metal type*	*Average as-received base-metal hardness*	*Average deposited weld-metal hardness*
A-40	A-40	126	200
A-40	A-55	150	208
A-40	A-70	223	225
A-40	A-40	148	185
A-40	A-40	155	184
A-55	A-55	150	214
A-55	A-70	145	235
A-70	A-70	223	272

Table 9—Variation in Mechanical Properties with Variations in Pipe and Filler-Metal Composition

Filler metal	*Base metal*	*Tensile strength, psi*	*Yield strength, psi*	*Elongation in 1 in., %*	*Bend tests*
A-40	A-40	52,400	40,200	21.0*	2T-190 deg
		51,300	40,200	20.4*	2T-180 deg
A-40	A-55	84,200	60,500	15	2T-180 deg
		83,300	59,900	22	2T-180 deg
		81,300	57,400	19	2T-180 deg
		80,900	59,000	20	2T-180 deg
A-40	A-70	90,145		10	2.5T-160 deg
		89,055		15	Cracks in A-70 base metal
		91,285		18	
		87,500		20	
A-55	A-55	79,460	58,645	18.5*	2T-180 deg
		78,265	56,735	18.5*	2T-180 deg

* Base-metal break.

contamination of titanium. A high-quality-grade argon or helium equivalent to 99.99% minimum inert-gas content is recommended.

Plate and Filler-Metal Composition

Much of the difficulty in obtaining reproducibility in the preliminary studies was thought to have been caused by variations in the base metal and filler wire. For most tests in the actual study, high-purity commercial A-55 or better pipe or plate, and the highest-purity A-40 wire available were used. As previously discussed, this combination yielded hardnesses of less than 190 DPH. If base metal of lower purity such as A-70 were used with the A-40 wire, the resulting weld metal would average 25 points higher in hardness. These hardnesses would, however, still be comparable to the base-metal hardnesses of these alloys.

The effects of variation in base-plate and filler-wire analyses were shown in various combinations in a series of pipe welds. The data from these welds are tabulated in Table 8. The first three lines show a gradual increase in hardness of the deposited weld metal with increasing base-metal impurity. The changes are not large, and when compared to the base-metal hardness, all welds would be considered acceptable.

A considerable increase in hardness is noted with the more impure filler wires. In these cases the weld metal is considerably harder than the base metal. Presented in Table 9 are the mechanical-property data for some of these welds.

Titanium A-40 or A-55 may be satisfactorily welded in air using filler wire of the same or purer composition. Titanium A-70 may be welded, but such welds will have limited ductility. In order that the complete weldment will have uniform properties, it is desirable to use a filler wire of higher purity than the base metal.

Portable Protective Devices

Two approaches were tried in an effort to develop portable protective devices. This effort was considered as being a backing effort. One procedure made use of plastic bags which were placed over the work and inflated by the purge gas. The other used trailers moving behind the torch to give the desired protection.

As was mentioned in the equipment section of this paper, the plastic bags, Fig. 3, completely enclosed the piece to be welded, which was in a fixed position. The torch and all other tools were placed in the bag before it was inflated. Air tools operated by inert gas were used for grinding and brushing of the welds between passes.

The first welds in the bag were made on 2-in. pipe with $\frac{1}{16}$-in. walls. Welds with hardnesses averaging 175 to 181 DPH were obtained and colors corresponded with those found in the air welding. The air content of the purged bag was found to be 0.5% (volumetric).

Multi-pass welds were made with 2½-in. Schedule 40 pipe. With these welds, the films on the first few passes varied from bright silver to golden, while these and other interference colors up to and including blue were found on the latter passes. The hardnesses varied from 180 to 189 DPH and showed no correlation with the color of the final pass.

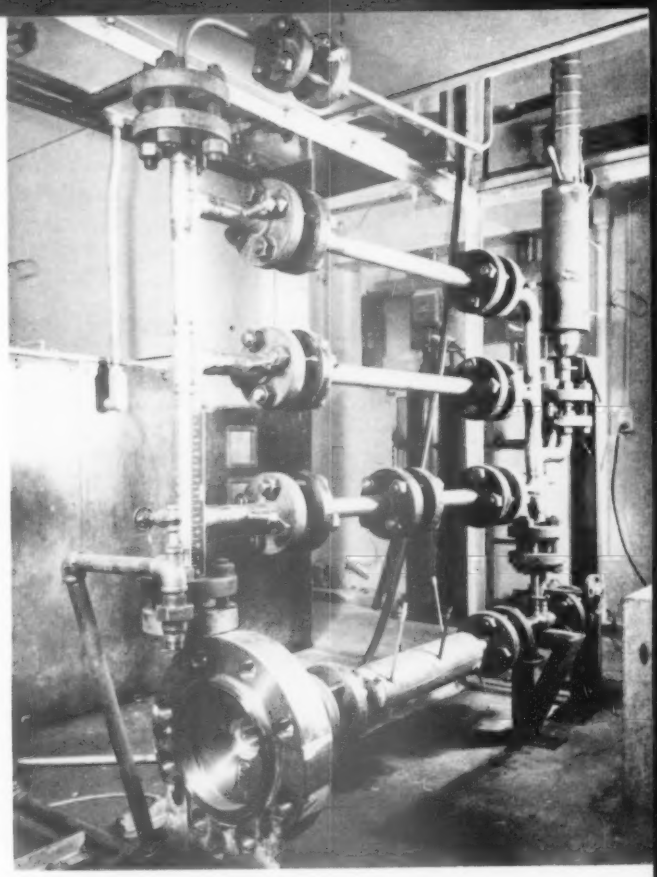


Fig. 10 Titanium corrosion loop

The use of such bags will produce sound acceptable titanium welds under field-welding conditions; however, with the development of the successful air-welding procedures, no additional work has been done with the bags.

Of the two types of trailers, one proved to be successful and the other did not. Data have already been presented in Tables 6 and 7, showing that successful welds can be made with the metallic trailers, Fig. 1. These trailers are, however, inconvenient to use in any except the flat position and must be made to match closely the contour of any curved surface. They are more useful for machine welds than for field welds.

The second type of trailer, Fig. 2, was made as an integral part of the torch cup. The cup was no longer round in cross section but had a rectangular bulge to the rear. With these cups, single-pass butt welds had hardnesses of greater than 200 DPH, indicating contamination. Turbulent gas flow was obtained from the torch to the shield. It appeared that some air was drawn in and contacted the molten metal, a fact which was confirmed by occasional electrode sparking.

Corrosion of Titanium

While no formal corrosion program on the variables in titanium welding has been pursued, many welds have been corrosion tested either as added samples or as structural members in the corrosion test rigs. They have been tested in acid-uranyl-sulfate solutions under

both static and dynamic conditions, at temperatures from boiling to 300° C. In general, titanium and austenitic stainless steels both have satisfactory corrosion resistance under mild conditions; however, under more severe conditions, i.e., concentrated solutions or high velocities, titanium was much better. No differences were noted in the corrosion of the various titanium welds or base plates and the corrosion rate did not seem to be affected by the weld quality.

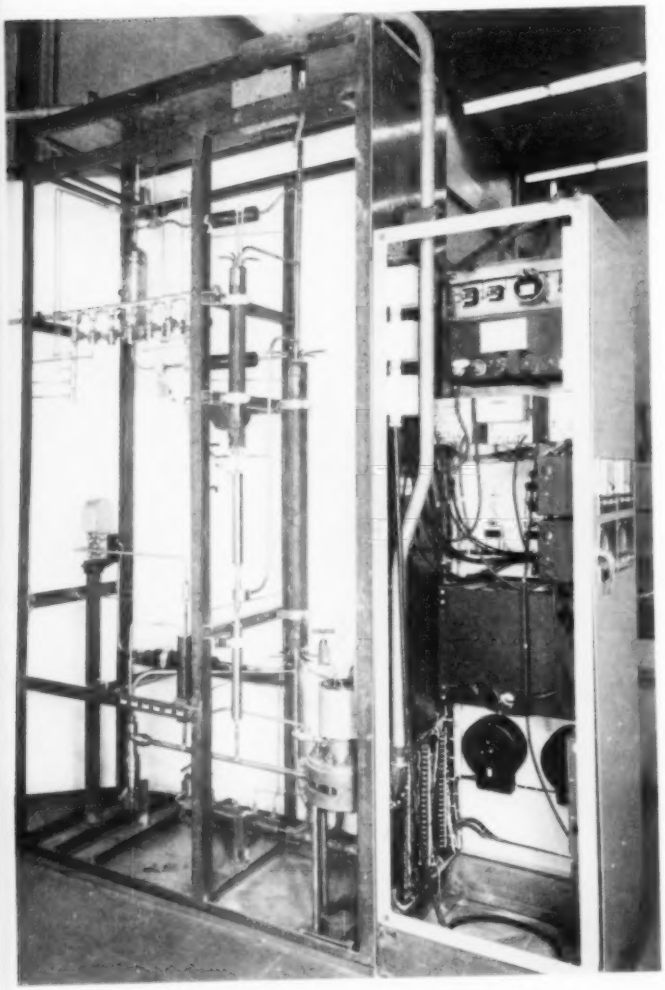


Fig. 11 Titanium loop for chemical separation

Fig. 12 In-pile titanium loop

Field Experience

The procedure has been proved in the construction of several titanium loops for use by development and corrosion groups. These loops are complex structures requiring many welds in a variety of sizes and locations. Different welders were used in the construction of each of these loops. Since destructive tests for contamination cannot be made of the field welds, a properly qualified and reliable welder is a necessity.

A corrosion testing loop with many titanium components and welds was built. It has circulated various uranyl-sulfate solutions at 250 to 300° C and 1000 to 2000 psi for three years. In this interval, not a single weld failure has occurred. A similar all-titanium loop, Fig. 10, was built and has operated without weld failure for one year. Another type of loop used for process development is shown in Fig. 11. Because of the toxic solutions used in this development, reliability was a must and no weld failures have been encountered.

The most complex structures made so far is an in-pile loop for the Corrosion Section. This loop circulated uranyl sulfate at approximately 300° C and 2000 psi inside a reactor. Since it was to operate inside a reactor, the space was extremely limited but yet the solutions would become highly radioactive making reliability an absolute must. Figure 12 shows such a loop constructed from A-55 titanium. This loop operated in pile at pressure and temperature without a materials failure for 660 hr after 370 hr of pretesting. A second such loop is now being built.

Conclusion

A procedure has been developed by which commercial unalloyed titanium pipe and plate may be successfully field welded with conventional inert-gas tungsten-arc equipment. The procedure depends upon maintaining low temperatures and careful control of the torch and backing inert gas during the welding operation. By using filler wire of higher purity than the base metal, it it is possible to achieve a weldment with uniform mechanical properties.

The procedure is applicable to the high-quality requirements of chemical and nuclear plants rather than to high-speed production welding. The price and quality of titanium welds made with this technique are comparable to those in which austenitic stainless steel is welded for nuclear applications.

The techniques have been proven in the construction of several titanium loop systems.

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FUNDAMENTALS OF BRAZING FOR ELEVATED-TEMPERATURE SERVICE

Available information is reviewed and some basic rules are established to help the fabricator obtain suitable brazed joints

BY M. D. BELLWARE

SYNOPSIS. The commercially available brazing alloys are grouped according to their usefulness for elevated-temperature service. In selecting a brazing alloy for elevated-temperature service two of the most important properties to be considered are strength and oxidation resistance. The classifications of the brazing alloys considered are silver-base, copper-base, manganese, gold and palladium-base and nickel-base. For service temperatures above about 1000° F, the nickel-base brazing alloys have produced the best results.

In all types of brazing, interalloying takes place between the base metal and the brazing alloy. With silver, copper, gold and palladium brazing alloys, the amount of alloying is usually slight. The nickel-base brazing alloys contain elements that promote rapid interalloying, particularly at the grain boundaries of the base metal. Short brazing times tend to reduce interalloying as well as liquation.

Proper cleaning of the parts prior to brazing is important. Oxides can be removed by pickling or by mechanical means. When brazing alloys in the form of fine powder are used, they are often mixed with a suitable vehicle such as acrylic-resin or methyl-cellulose. These binders leave practically no residue after brazing. Heating is usually accomplished in a furnace because it is desirable to braze in a reducing atmosphere.

Some means must be provided to keep the parts free from oxidation during brazing. A reducing atmosphere such as dry hydrogen is normally used. However, brazing can be done in a vacuum, or using a high-temperature flux. When aluminum or titanium is present it is sometimes necessary to nickel plate the parts prior to brazing in order to avoid oxidation.

Introduction

For the past several years, there has been a continuing increase in need for brazed joints that will withstand higher and higher temperatures. Although brazed joints

M. D. Bellware is associated with the Mechanical Engineering Section of the International Nickel Co., Inc.

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Demonstrating lightness of honeycomb panel

Fig. 1 Honeycomb panel that will be joined by brazing. These structures have an exceptionally high strength-weight ratio

Fig. 2 An experimental jet-turbine blade fabricated by high-temperature brazing

have been used at service temperatures in the neighborhood of 2000° F, the technology for consistently producing satisfactory joints has not yet been fully developed. Considerable strides have been made through research and development as well as experimental shop work, but because the field is quite new there is only a limited amount of practical experience from which to draw. Because of this, there are but few fixed rules to establish the conditions for brazing that will give predictable results. Conditions that are satisfactory the first time do not necessarily produce satisfactory results the next time. One laboratory facetiously reports that an almanac should be consulted before brazing, as failures will surely result during certain signs of the zodiac. While this advice has been offered in a humorous vein, we believe it points up some of the troubles that have beset this infant method of joining.

In order to foster a somewhat more logical approach than the one just mentioned, it was felt desirable to set down some of the known facts and criteria used to help obtain predictable results. This paper is not intended as a disclosure of any new discoveries. The purpose is merely to assemble some of the available information and attempt to establish a few ground rules which will help the fabricator obtain suitable brazed joints.

The terms "high-temperature brazing" and "brazing for elevated-temperature service" are themselves somewhat ambiguous. The first indicates that the brazing is done at a high temperature but does not necessarily imply a high service temperature, and neither of the terms gives any indication of how high is "high temperature." For the purposes of this paper, we will arbitrarily choose a temperature of about 500° F, as a dividing line between low-temperature and elevated-temperature service.

Applications

The applications in which high-temperature brazing can be used vary quite widely. One of the most publicized uses has been in the fabrication of honeycomb panels for the aircraft industry as shown in Fig. 1. These panels have a very high strength-weight ratio and have been made in contoured shapes and lengths up to 12 ft. Other applications in the aircraft industry have included complicated assemblies that cannot be readily fabricated by welding. Such an example is the experimental turbine blade shown in Fig. 2. Fre-

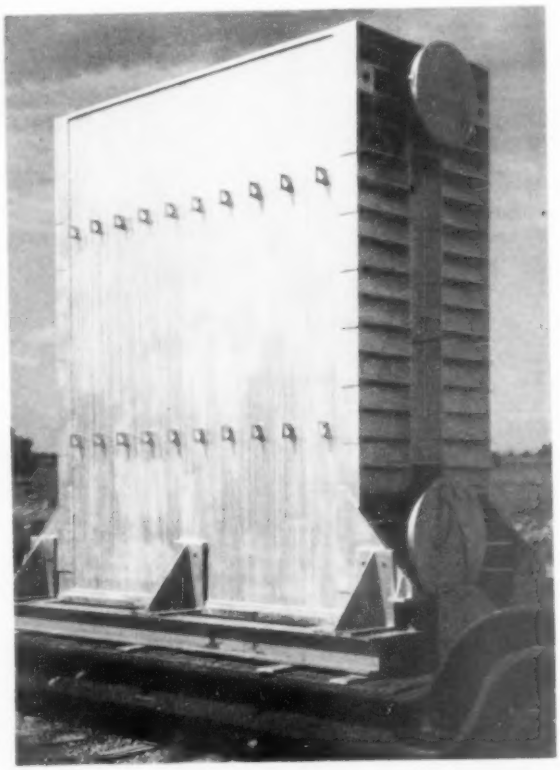

Fig. 3 Large heat exchanger for elevated-temperature service fabricated by brazing. (Courtesy Harrison Radiator Co.)

quently heat exchangers are of such configuration that they do not readily lend themselves to brazed construction. Nevertheless, plate-type heat exchangers of all sizes have been fabricated by brazing. Figure 3 shows a large heat regenerator made of low-alloy steel and joined by welding and brazing. Small tube-type exchangers have also been fabricated by brazing.

These are but a few of the many proven applications. High-temperature brazing has potentialities in virtually every field where the finished product must be able to withstand the rigors of elevated operating temperatures.

Brazing Alloys

In selecting a brazing alloy for elevated-temperature service, two of the most important properties to be considered are strength and oxidation resistance. It is understood, of course, that the alloy should also possess the characteristics desirable of any brazing material, such as good wettability, ability to flow, ductility, relatively low cost, etc. Since the conditions of service will vary for different applications, it is not practical to set specific limits for service temperatures to which strict adherence must be maintained. The life expectancy of the parts should be considered as well as strength requirements, corrosion resistance and the tendency of the brazing material to alloy excessively with the base metal.

An almost infinite number of brazing alloys has been considered for elevated-temperature service. It would be impossible to list each one of these so we have instead lumped them into categories and will attempt to cite a few general characteristics of each group. Table 1 lists several commercially available alloys and indicates a temperature above which their usefulness is limited.

Silver-Base Alloys

The strength and oxidation resistance of the more common silver-base alloys drops off rather rapidly as the temperature increases above 300° F. The temperature limit for these materials has customarily been set at about 500° F. However, there are a few notable exceptions among these alloys. Two of these are the 72% silver–28% copper, and the 85% silver–15% manganese alloys which are useful at temperatures up to about 700-800° F. One investigator's results[3] indicated that, if heated in still air to 700° F for 1000 hr, the silver-copper alloy would oxidize to a depth of about 0.0026 in.; whereas the silver-manganese alloy would oxidize to only about 0.0003 in. Unfortunately, silver-manganese is sometimes susceptible to crevice corrosion attack, even in mild atmospheres.

These alloys do not penetrate any appreciable distance into the base metal; a feature that has made them quite useful for joints in thin materials such as honeycomb. They are quite ductile and can easily be rolled into thin sheet and drawn into wire. Foil as thin as 0.002 in. is commercially available. Lithium additions up to about one percent have been used to promote wetting of the base metal with these alloys.

Other silver-base alloys that show considerable promise are those containing palladium and manganese. Two of the commercially available alloys are 64% silver–33% palladium–3% manganese, and 75% silver–20% palladium–5% manganese. These alloys too, are ductile and can be rolled and drawn quite readily. Short-time shear tests at 800° C (1472° F) have indicated strengths in the range of 7000 to 11,000 psi. However, at this temperature the oxidation resistance is poor.

Copper-Base Alloys

Copper and copper alloys have been used as brazing material for many years. They have good strength at moderately elevated temperatures but oxidation resistance is usually satisfactory no higher than about 850-900° F. Copper alloys containing about 10% silver, and sometimes up to 1% lithium, have been used for honeycomb fabrication.

Manganese-, Gold- and Palladium-Base Alloys

Other alloys to be considered for use in this tempera-

Table 1—Some Commercially Available Brazing Alloys

	Nominal composition, %									Approximate brazing temperature, °F	
No.	Ag	Cu	Pd	Ni	Cr	Si	B	Mn	Other		Remarks
1	72	28								1450-1600	Useful for service to about 700° F
2	85							15		1800-1900	Useful for service to about 800° F
3	75		20					5		2050	Good strength up to about 1100-1200° F
4	64		33					3		2200-2250	Good strength up to about 1100-1200° F
5		100								2050	Oxidation resistance poor above 900° F
6				32				68		1850-2000	Oxidation resistance poor above 1000° F
7				90					10 P	1750-1900	Oxidation resistance poor above 1300° F
8				91		4.5	3			1850-2000	Excellent fluidity, good oxidation resistance to about 1700° F
9				93		4	2.6			1950-2150	General purpose alloy, good oxidation resistance to about 1700° F
10				82	7	4	3		3 Fe	1850-2000	Chromium addition gives better oxidation resistance than Ni-Si-B alloys
11				71	16.5	4	3.8		1 Fe	1900-2100	High Cr content provides maximum high-temperature oxidation resistance
12				71	19	10				2175	Oxidation resistance good up to about 1700-1800° F

ture neighborhood are 68% manganese – 32% nickel and 82% gold – 18% nickel. The percentages shown provide approximately the lowest melting points that can be obtained in the two binary systems. Chromium is sometimes added to the gold-nickel alloy to increase the oxidation resistance.

Various palladium-base alloys have been considered but there are little data available. An alloy of 92% palladium – 8% aluminum showed very good oxidation resistance as high as 1700° F.[2] Another composition, 80% palladium – 14.5% silver – 5.5% aluminum, is commercially available.

Nickel-Base Brazing Alloys

For service temperatures exceeding about 1000° F the nickel-base brazing alloys should be considered. The characteristics of nickel make it a good starting point in developing brazing alloys to withstand high service temperatures. It is itself quite ductile and, with proper additions of other elements, has excellent strength and oxidation resistance as well as corrosion resistance at elevated temperatures. Nickel melts above 2600° F, which makes it necessary to add elements that will lower the melting point. The elements commonly used as alloying additions for brazing alloys are chromium, silicon, boron, phosphorus and carbon. The primary function of chromium is to increase the oxidation resistance and strength, whereas the other elements lower the melting temperature. The nickel-base alloys in use are all low in ductility, making it impossible to produce them in wrought form. They are generally supplied as a fine powder. However, simulated wrought forms, particularly wire, are made available by some producers by combining the metal powder with a plastic, and extruding the mixture. There has been a countless number of nickel-base brazing alloys proposed, but we will consider only a few that are representative of the major types.

The nickel-phosphorus eutectic, consisting of 10–12% phosphorus, balance nickel, has been successful for service temperatures as high as perhaps 1300° F. The phosphorus not only lowers the melting temperature of nickel to about 1625° F, but also acts as a deoxidizer so that partially combusted fuel gas can be used as the protective atmosphere when brazing many base materials. This alloy also has relatively low cost, making it attractive for applications involving large quantities of brazing material. It has found its principal use to date in large heat exchangers made of carbon and low-alloy steels. These assemblies have previously been brazed with copper which limited the service temperature to about 900° F, and in effect limited the operating efficiency of the unit.

Another popular high-nickel brazing alloy meets Aeronautical Material Specification (AMS) 4778. It is produced by adding both silicon and boron to nickel in order to reduce the brazing temperature. Its liquidus temperature, depending upon the composition, varies from about 1820 to 1930° F. It presumably can be used for service temperatures somewhat higher than the nickel-phosphorus composition.

For applications involving very high temperatures, those nickel-base alloys containing chromium are desirable. The amount of chromium may be as high as 20%. AMS Specification 4775 covers an alloy containing 16% chromium, to which silicon, boron and carbon have been added to lower the melting temperature. This alloy has exceptionally good strength and oxidation resistance at elevated temperatures. It has been used for temperatures as high as 1800–2000° F.

Because boron penetrates the grain boundaries of the base metal so rapidly, and because it is detrimental in many atomic power applications, efforts have been made to develop high-temperature alloys without boron. The most predominant of these has been an alloy containing a nominal 19% chromium and 10% silicon.

Joint Design

The design for brazing for elevated-temperature service will, in general, make use of the same criteria as used in silver brazing. A lap-type joint should be used wherever practicable. The clearance between the mating parts to be brazed should be controlled to some predetermined spacing. "Zero" clearance, that is to say no intentional gap provided between the mating surfaces to be joined, has been shown to produce good results with nickel- and gold-base alloys.[3] Past experience would also indicate this to be desirable when brazing with copper. A sufficient quantity of alloy must be present to fill the crevice completely and form fillets at the edges, but excessive alloy is undesirable because it will tend to increase penetration into the base metal.

Although many of the high-temperature brazing alloys have low ductility, the brazed joints themselves are adequate for many applications. There is presently much confusion concerning the strength of brazed joints, due primarily to the lack of a standard test specimen by which all investigators can evaluate their results. By altering the design of the test specimen, it

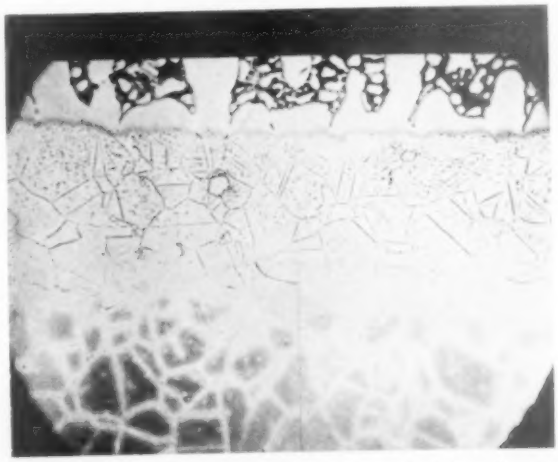

Fig. 4 Nickel-base brazing alloy containing boron, overlayed on 18–8 stainless steel. Note intergranular penetration of boron into the base metal

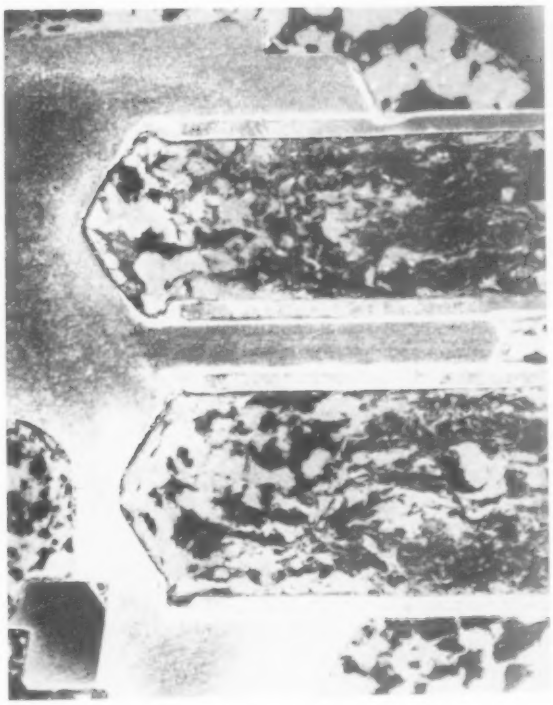

Fig. 5 Copper-brazed joint between stainless steel and Inconel tubes. The copper has penetrated into the $\frac{1}{32}$-in. wall of the tubing because of excessively long brazing time

is possible to obtain a marked variance in the apparent strength of the brazing alloy. To interpret test data properly, it is necessary to take into consideration the type of specimen upon which the data was obtained. Even when this is known there is considerable room for doubt as to how the data can best be applied to any particular brazement design.

Interalloying

In all types of brazing, interalloying takes place between the base metal and brazing alloy. The extent to which this occurs depends upon the materials involved as well as brazing temperature and time at temperature. With silver, copper, gold and palladium brazing alloys, the amount of alloying is usually slight. However, the nickel-base brazing alloys contain elements that promote rapid interalloying, particularly at the grain boundaries of the base metal. An example of this intergranular "attack" is shown in Fig. 4. This cross section shows a nickel-base brazing alloy containing boron that has been fused to the surface of an 18-8 stainless steel. The penetration of the boron into the base material is indicated by the darkly etched grain boundaries. This type of penetration can occur quite rapidly and is most detrimental in thin members such as honeycomb panels. Alloys that exhibit this trait have been termed "aggressive."

The effect of time on interalloying is indicated in Fig. 5, which shows a copper-brazed joint between nickel-chromium-iron alloy tubes and a Type 347 stainless-steel manifold. In this particular case, the parts were mounted on a bulky jig having a thick cross section, which required several hours' furnace time in order to bring the entire assembly to brazing temperature. During the relatively long time at high temperature, the copper penetrated completely through some of the tubes. The problem was solved by brazing each joint individually by induction heating to obtain a shorter brazing cycle.

Interalloying, however, is not always deleterious. It can even be helpful on heavy sections. As elements such as boron, silicon and phosphorus are consumed by alloying with the base metal, the melting temperature of the brazing alloy increases. This phenomenon frequently results in a joint that cannot be remelted without going to a higher temperature than the original brazing temperature. In service, such joints have exhibited useful strength up to, or even exceeding, the original brazing temperature.

In making brazed joints, it is desirable to keep the brazing time as short as practicable, not only to reduce interalloying, but also to reduce liquation. Slow heating through the melting range will cause the lower melting portion of the alloy to become fluid and flow before the higher-melting constituents melt. A "skull" of the higher-melting constituents will then be left behind and may not flow even when the parts have reached the maximum temperature. Since only part of the filler metal has been made available to the joint, incomplete filling may result. To overcome this phenomenon, it is sometimes desirable, particularly when dealing with thin sections, to use an exceptionally high brazing temperature and short brazing time. If the brazing alloy is taken through the "mushy" temperature range fast enough, the constituents will not separate. It has sometimes been helpful to use a two-step heating cycle to reduce the length of time the brazing alloy is in the "mushy" zone. The furnace can be brought up to a temperature just below the solidus of the brazing alloy and held until a uniform temperature is obtained throughout the assembly. The temperature can then be increased so as to heat the parts to the liquidus rapidly. This procedure has been successful in some instances but can be harmful from the standpoint of oxide formation before the brazing alloy flows.

Preparation for Brazing

Cleanliness

Cleanliness is of vital importance to any brazing operation. Molten brazing alloys will adhere only to chemically clean metal and not to oxides of metals, dirt or other foreign material. Therefore, it is important that oxides and all foreign matter be removed from parts which are to be brazed. In addition, if a high-nickel alloy is involved, there is danger of embrittling attack by sulfur and low-melting point metals, particularly lead, at elevated temperatures. Such substances as oil, grease, paint, marking pencils, drawing or cutting lubricants, and others, contain enough sulfur or

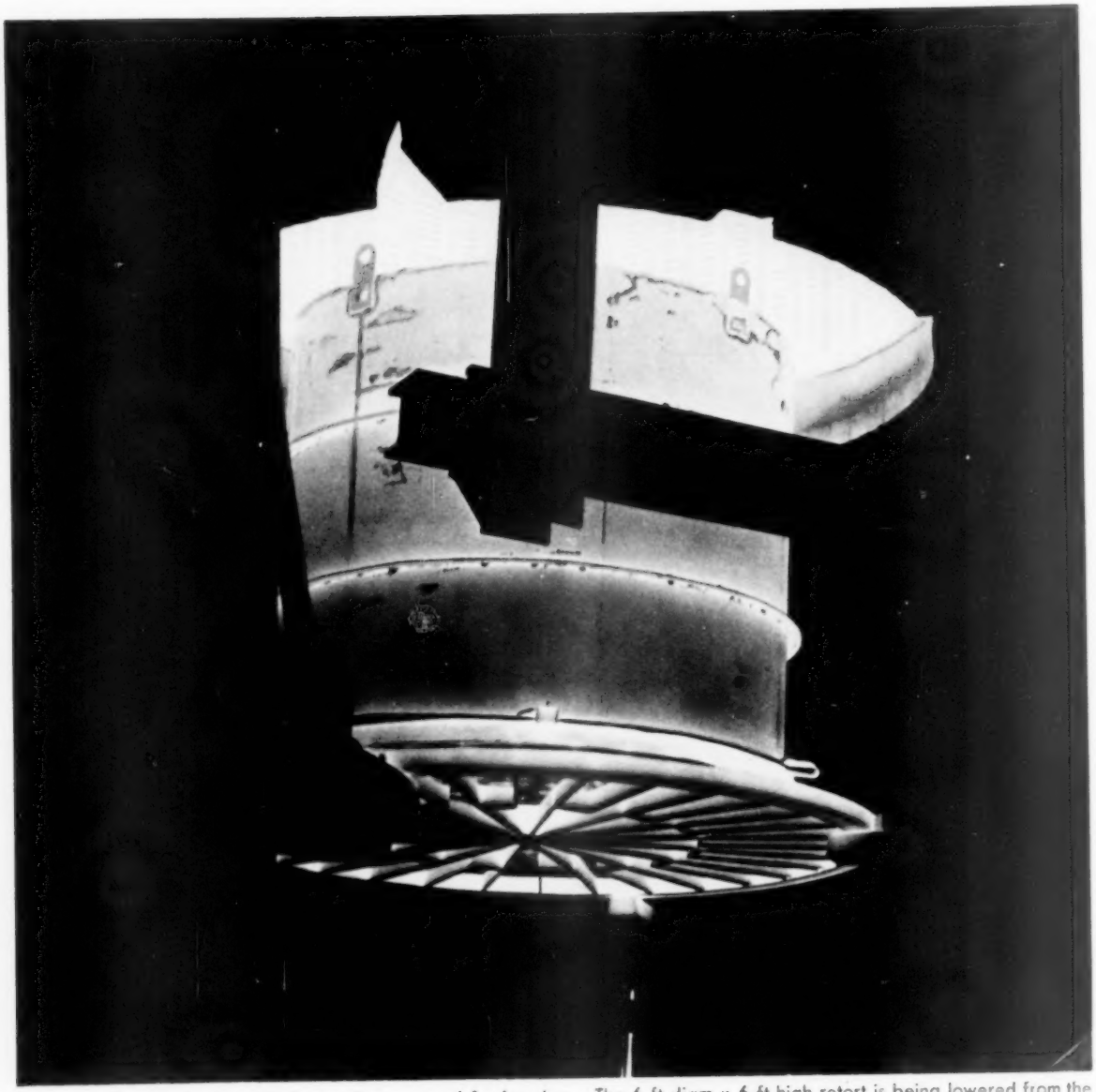

Fig. 6 Example of a large bell-type furnace used for brazing. The 6-ft diam x 6-ft high retort is being lowered from the furnace after a brazing cycle

lead to cause embrittlement of nickel at brazing temperatures.

Grease or oil may be removed by standard degreasing methods employing vapor degreasers, alkaline degreasers or merely by wiping or immersing the parts with, or in, a suitable solvent. Wiping or immersing is satisfactory for a small number of parts, but contamination of the rag or solvent may merely redistribute grease or oil rather than remove it, if these methods are to be used for large production.

Oxides will not be removed by degreasing alone. They may be removed by pickling or by mechanical means such as grinding, emery cloth or shotblasting. Wire brushing is not always satisfactory since the oxide films on many high-temperature alloys are tenacious and will not be removed completely. Blast cleaning should also be used with caution as particles of the blasting material are likely to become embedded in the surface and interfere with flow of the brazing alloy. Sandblasting and shotblasting with alumina should be avoided. In all cases it is advisable to clean with a suitable solvent or detergent after blasting.

Applying the Alloy

The placement of the brazing alloy with respect to the joint is critical. The alloy should be placed in, or as near as possible to, the joint. If necessary, wells or other receptacles should be provided to retain the alloy during assembly and heating. Flow of the brazing alloy is aided by capillary action but it is also helpful to take advantage of gravity wherever possible by

allowing the alloy to flow down hill.

When the brazing alloy is in the form of a fine powder, it is often mixed with a suitable vehicle to form a slurry which can be brushed, sprayed or extruded onto the parts to be joined. For small parts where the alloy must be placed accurately, an eye dropper or a hypodermic needle has been used. For larger parts, spraying, brushing or dipping is generally desirable.

After applying the slurry, the vehicle should be allowed to dry before furnacing. Binders such as acrylic resins are flammable until dried but otherwise have good characteristics for brazing. Methyl-cellulose binders are water-base and have been used quite satisfactorily. The vehicle chosen should exhibit the characteristic of leaving practically no residue after brazing. If a paste flux is to be employed, it may be substituted for binder. Powder fluxes such as borax may be added to the slurry.

Heating Methods

Furnace brazing is most generally used for the high-temperature brazing alloys. This is because it is usually desirable to braze in a reducing atmosphere. However, it is possible, on some joints, to achieve usable results with an oxyacetylene torch and a high-temperature flux. Induction heating has also been quite successful when used in conjunction with either a flux or a reducing atmosphere. The rapid heating obtained is conducive to good brazed joints.

Furnace brazing must be done in either a retort or muffle because of the stringent atmosphere requirements. Literally all types of furnaces have been used, ranging from small tube-type furnaces to the large bell-type shown in Fig. 6. This furnace is suspended 35 ft above the floor and is loaded by elevator. The retort measures 6 ft high and 6 ft in diameter. In continuous-belt furnaces there is always the possibility of contamination by air. Therefore, these furnaces are not generally used when the atmosphere has to meet extreme requirements of purity. However, excellent results have been obtained in a hump-mesh-belt furnace. Most batch-type furnaces can easily be used by placing the parts to be brazed inside a retort. An atmosphere such as combusted city gas may then be used to surround the retort and protect the heating elements but not come in contact with the work.

The details of construction of the retort require special attention. There should be a slight positive pressure in the retort to prevent mixing of air or furnace atmosphere with the dry hydrogen or other reducing gas inside the retort. Sand seals employing alumina instead of silica have been used successfully. Silica may also be used but there is a danger that it will be reduced by dry hydrogen, producing moisture. Mechanical seals have also been satisfactorily employed.

The retort must be carefully and thoroughly purged of all air prior to insertion in the furnace or an explosion may result.

Jigs and fixtures should be made as light as possible, or eliminated completely whenever the parts can be made self-jigging. Heavy fixtures tend to rob the parts of heat, requiring longer brazing cycles to be used. Fixtures may be made of metals, ceramics or graphite. Graphite should not be used in dry-hydrogen atmospheres because of the formation of hydrocarbon gases which can transfer carbon to the parts being brazed. Even in inert atmospheres and vacuum, the carbon must be prevented from coming into contact with the work in order to avoid carburization. Stainless steel or sulfur-free asbestos slip sheets between the carbon and the work will help avoid this difficulty.

Several ceramic materials have been used for fixtures. They have the ability to withstand high temperatures, and have low thermal coefficients of expansion. However, they have low resistance to both mechanical and thermal shock.

If metal fixtures or boats are to be used in the brazing chamber it is usually desirable to have these parts relatively free from oxide before commencing the brazing cycle. If a heavy oxide is present, it will tend to be reduced by the atmosphere, with the result that a higher dew-point gas is supplied to the parts to be brazed.

Reduction of Oxides

A thin oxide film is always present on any metal or alloy and oxidation tends to increase rapidly at high temperatures. Therefore, some means must be provided to keep the parts free from these oxides during brazing.

Atmospheres

Although there are several methods of handling oxide formation, most high-temperature brazing is accomplished using a reducing atmosphere. The type of atmosphere required for a particular application will depend upon the brazing temperature as well as the composition of both the base metal and the brazing alloy. Those materials containing elements which form the most stable oxides will require the most stringent atmospheres. Figure 7 shows the metal-metal oxide equilibria for several elements in dry-hydrogen atmosphere. Hydrogen can be dried consistently on a production basis to about −80 to −100 F

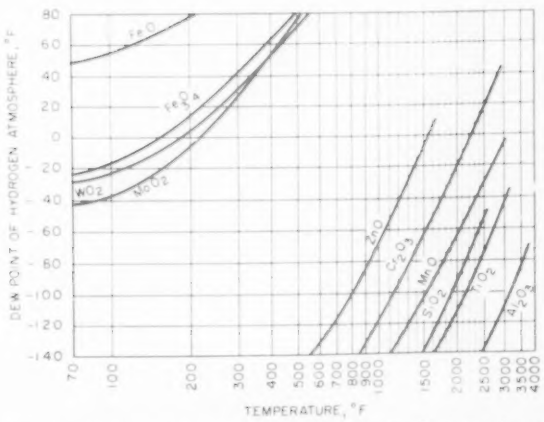

Fig. 7 Metal-metal oxide equilibria in hydrogen atmospheres[5]

Table 2—Suggested Atmosphere for Brazing

Element	Type of atmosphere: Combusted fuel gas (decarburizing)	Dried combusted fuel gas (−30° F dew point)	Cylinder hydrogen	Dissociated ammonia	Inert gas (argon, helium, etc.)	Dry hydrogen (−80° F dew point)	Vacuum	Flux
AWS brazing atmosphere type No.	2	3	6	5	9	7	10	
Copper, cobalt, nickel iron, palladium	X	X	X	X	X	X	X	X
Chromium				X	X	X	X	X
Manganese				X	X	X	X	X
Silicon						X	X	X
Titanium							X	X
Aluminum							X	X

This table indicates the methods which may be employed to reduce the oxides of several elements involved in high-temperature brazing. The atmosphere required for brazing any joint will depend upon the composition of both the brazing alloy and the base material. However, when an element is present in quantities less than about 0.5%, it usually need not be considered. This table is not intended to set forth any hard and fast rules, but only serves as a guide in the selection of the proper brazing conditions. Factors such as nitriding and carburizing can have a major influence on the choice of an atmosphere. Also, if elements such as lithium and phosphorus are present, they may act as deoxidizers and therefore permit the use of a less reducing atmosphere than is indicated.

dew point. From this chart then, it becomes obvious that if aluminum or titanium are present in any appreciable amounts, the oxides must be handled by some method other than a dry-hydrogen gas. These methods will be discussed later. Most of the other elements encountered in high-temperature brazing can easily be reduced by dry hydrogen.

Cylinder hydrogen can be purified by passing it through a palladium catalyst to cause any oxygen present to combine with hydrogen to form water vapor, and removing the water vapor by passing the gas through copper coils immersed in liquid nitrogen, or through a drying agent such as silica gel, alumina, or the more recently developed molecular sieves. This newer drying material consists of pellets of sodium-aluminum silicate. Some users have claimed to have obtained dew points below −100° F using the molecular sieves. Unfortunately, it is difficult, if not impossible, to measure accurately such small quantities of moisture in a gas.

The importance of rapid heating should again be emphasized because oxidation can occur at low temperatures even in extremely dry atmospheres. According to Fig. 7, Cr_2O_3 will continue to form in hydrogen having a −80° F dewpoint until the temperature reaches about 1350° F. The longer a chromium-containing alloy dwells within this temperature range, the greater will be the oxidation.

Other atmospheres, including dried combusted fuel gas, dissociated ammonia and inert gas such as helium and argon, have been used with varying degrees of success. Table 2 shows some of the elements commonly used in both the base metals and brazing alloys for elevated-temperature service. It also shows several types of atmospheres and indicates those that will reduce various metal oxides. This table is intended only as a general guide in the selection of proper brazing conditions and should not be used without due consideration of such factors as nitriding and carburizing as well as considering the presence of deoxidizing elements such as fluoride, boron, lithium and phosphorus. Nitriding and carburizing can be very harmful during brazing, particularly when thin sections are being joined.

In some instances two or more of the above atmospheres have been combined. Argon containing 3 or 4% hydrogen has been used with very good results. This combination has the distinct advantage of being non-explosive when mixed with air.

Vacuum

Vacuum brazing can be used for most metals, even those containing aluminum and titanium. It cannot, of course, be used when elements having low vapor pressure are present. These are elements such as zinc, cadmium, phosphorus and lithium, to mention a few. If alloys containing aluminum or titanium are to be brazed under vacuum, the pressure must be in the neighborhood of one micron. However, it has been reported that good results can be obtained at higher pressures if the chamber is first purged with purified argon.

Fluxes

There are a number of commercial fluxes available that will produce quite satisfactory results. However, all flux residue must be removed after brazing to avoid corrosive attack of the base metal. Many joints are inaccessible after the parts are assembled which rules out the use of a flux. In addition, the flux residue is glasslike and quite tenacious, requiring grinding, chipping or sandblasting to achieve complete removal. Furthermore, the flux often becomes entrapped in the joint. Borax or boric anhydride have also been used but are not as effective as the fluoride-containing commercial fluxes. Excellent results have been reported, however, using potassium pentaborate.

Many types of gaseous fluxes have been investigated. Sufficient oxide removal has been effected by simply

placing a small container of sodium fluoride or calcium fluoride in the brazing chamber. Other gaseous fluxes that have been tried are potassium tetraborate, boron trifluoride and silicon tetrafluoride. These fluxes have not been fully evaluated.

As was mentioned earlier, oxide removal can be facilitated by adding phosphorus to the brazing alloy. Lithium has also been used extensively for this purpose, particularly in the copper and silver-base alloys. These elements form oxides that float off, or are vaporized, and do not interfere with wetting. It has been reported[3] that vapors of the alkaline metals, lithium, sodium, potassium, rubidium and cesium, will reduce oxides. These elements can be placed in an open container in the brazing retort and will vaporize under a vacuum of 200 to 800 microns.

Plating

Because of the difficulty in removing aluminum and titanium oxides, alloys containing these elements in excess of about 0.5% are frequently plated with nickel or iron to a thickness of a least 0.0005 in. before brazing. The plating will protect the base metal from oxidation and will require only a moderately reducing atmosphere for subsequent brazing. There is a preference among most fabricators for nickel plating, primarily because of the ease in obtaining a satisfactory bond between the plate and the base metal. The thickness of the plating required will depend upon the brazing conditions, especially the time required to make the joint. Given enough time at temperature, the aluminum or titanium will diffuse through to the surface and the plating will not be effective.

Pretreatment

Still another method that has been used for joining alloys containing aluminum and titanium has been to treat the base metal with a selective oxidation and pickle before brazing. Aggen, Long and Reynolds[5] heated the base material to brazing temperature in an atmosphere of hydrogen at −40° F dew point. It was theorized that this was adequate to minimize oxidation of all elements except aluminum and titanium. These caused a thin, dark oxide to form which could be removed by a finish pickling treatment. This, in effect, left the surface impoverished of aluminum and titanium and permitted subsequent brazing in a dry-hydrogen atmosphere.

Conclusions

Predictable results can be obtained, within limits, when brazing for elevated-temperature service. However, it is necessary to consider all of the service conditions, especially the requirements for strength, oxidation resistance, length of service life and base metals involved. Brazing alloys are available that will furnish reasonably good properties up to about 2000° F. The nickel-base brazing alloys show considerable promise for use at such temperatures. Unfortunately, they are somewhat lacking in ductility and they are "aggressive."

Some means must be provided to inhibit the formation of oxides during brazing. This can be done through the use of a suitable atmosphere or flux. The difficult oxides of aluminum and titanium can be avoided by several methods. Nickel plating has been the most common method used when a flux cannot be employed. Heating may be accomplished with any of the processes normally used for brazing but the heating rate should be rapid.

Additional development work is certainly desirable on new brazing alloys that will stand up at temperatures of 2000° F and higher. The ideal high-temperature brazing alloy is one that would have excellent strength and oxidation resistance at elevated temperatures, as well as good ductility at all temperatures. It should not penetrate deeply into the base material and it should be self-fluxing when used in a dry-hydrogen atmosphere. Further investigation should be made of the effects on base metals of the various alloying elements in the nickel-base brazing alloys. The influence of carbon, boron, silicon and phosphorus on joint properties is not fully known. It would be particularly interesting to learn more about the influence of each of these elements after exposure at various time and temperatures.

A standard test for evaluating the strength of brazing alloys is urgently needed, in order to correlate more closely data from various investigators. The greatest need is for data on stress rupture strength and oxidation resistance.

The excellent research and development contributions that have been made by many individuals have placed high-temperature brazing on a sound footing. Nevertheless, this writer believes we have only begun to scratch the surface in establishing the importance of this versatile method of joining.

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HOW GOOD IS YOUR WELDER POWER SUPPLY?

Relatively simple electronic counter developed to indicate the frequency with which excessive voltage drops occur

BY A. C. JOHNSON AND F. E. DONATHAN

An electronic voltage-drop counter which makes possible the determination of the number of voltage drops of any preselected magnitude and duration which occur at the point of its connection to a power system

Introduction

Most engineers concerned with the problem of supplying power to resistance-welding equipment would be hard pressed to give a quantitative answer to this question. The answer probably would be a vague generality which would be difficult or impossible to support with factual data.

The authors, with the assistance and cooperation of the Superior Coach Corp., have developed an instrument which will permit a specific, quantitative evaluation of the quality of such a power system in terms understandable to those not technically trained. This instrument is basically a counter which will record, in the period for which it is used, the number of times that the voltage on a system drops to a preselected level for a preselected duration. With some understanding of the effect of voltage variations on the quality of resistance welds, it is possible to make a statement that x% of the welds made in a given period are defective as a result of voltage variation.

In 1943 one of the authors contributed to a paper* in which methods were developed for determining such information mathematically. The formulas, unfortunately, are somewhat unwieldy and at best must be based on certain simplifying assumptions. Because of the considerations of probability on which such conditions depend, the results are mathematical predictions rather than a history of actual occurrences, and a duplication of the random circumstances which causes the voltage fluctuations for experimental or test purposes are practically impossible.

While these difficulties do not detract from the value of such formulas for designing proposed installations, the use of an instrument which provides an historical record without laborious computations is of considerably more benefit in evaluating existing systems.

The Problem

In order to design or evaluate these distribution systems, a statement of the problem involved and a clear understanding of the pertinent factors is, of course, necessary. It has been the experience of the authors that many otherwise qualified power engineers are lacking in an understanding of the principles involved in the loading of a system by resistance welders. In addition, many of those who become concerned with this subject are tooling engineers or managerial personnel who are not familiar with the applicable electrical engineering concepts. For that reason, the characteristics of the welding equipment and its associated power supply are discussed below, and in as nontechnical a fashion as the subject will permit.

A. *The Nature of the Load*

Most resistance welders, for which power supply is any problem, operate by passing currents of the order of 5000 to 100,000 amp through the work for durations of from 5 to 60 cycles ($\frac{1}{12}$ to 1 sec). The voltage necessary to circulate this current would probably be in the range of from one to thirty volts. For the most part, these impulses will appear on the distribution system as

A. C. Johnson is Indianapolis representative of Progressive Welder Sales Co., Pontiac, Mich. **F. E. Donathan** is development and welding engineer, Superior Coach Corp., Lima, Ohio.

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* "The Design of Low-Voltage Welding Power Distribution," Adams, C. A., Fetcher, J., and Johnson, A. C., AIEE Transactions, 63 (1944).

low power factor, single-phase loads, repeated at irregular intervals. Machines having a number of welding circuits may have them so arranged as to divide the impulses between the phases, either simultaneously or successively. Special controls and machine designs are available which will divide the load in a single-phase, single-circuit welder between the phases, or which will improve the power factor and reduce the demand.

B. Terminology

The terms necessary to discuss the effect of a welder on the power system are as follows:

1. *Demand.* This characteristic of the machine, usually expressed in kva, is the product of the voltage and current at its terminals (divided by 1000 for convenience). The kw demand is kva demand × power factor. The kw demand is the power or the rate at which energy is supplied to the machine by the system. The kva demand includes energy borrowed from and paid back to the system 120 times per sec. Since a typical power factor might be 30%, the kva demand will be of the order of three times the kw demand.

2. *Duty Cycle.* This is the percentage of time that the demand exists, or the ratio of the time "on" to the time "on plus off." Obviously, this is not an explicit term since its value will be affected by the length of time under consideration. If one is concerned with devices that heat up rapidly (have a small averaging time), such as an ignitron tube or a fuse, he would be interested in the duty cycle calculated on the basis of a few seconds or perhaps even within the duration of one weld impulse, in which case the duty cycle would be 100%. For the purposes of this discussion, in which we are concerned with equipment having considerable thermal capacity, such as transformers and feeders, the duty cycle is the average over a period of a few hours. This duty cycle might be 1% or less for a projection welder, 5 or 10% for a rapidly operating spot welder, and 50 or 100% for a seam welder.

3. *Power Factor.* This may be defined as the ratio of the power at the terminals to the demand; that is kw/kva. It may also be defined as the cosine of the angle between the current and voltage waves or the vectors which can be used to represent them. If the current is nonsinusoidal, as may be the case when electronic heat control is used, this latter definition is fictitious.

4. *Voltage Drop.* This is the reduction in voltage which occurs at the machine terminals, expressed in volts or in percentage of the line voltage, as a result of the current of the machine flowing through the impedance of the power system. Voltage drops will also occur as the result of currents from other loads flowing through parts of the system common to both.

5. *Voltage-Drop Variation or Voltage Variation,* as the case may be, at the terminals of a welder, is the variation produced as a result of the operation of other equipment connected to or supplying voltage for the system. For a given setup, the voltage drops caused by any one machine at its own terminals will be identical each time it welds, and consequently will have no effect upon the weld quality of that welder. The distinction between voltage drop and voltage-drop variation is quite important, since within the limits of satisfactory operation of controls, relays, etc. quite an appreciable voltage drop can be tolerated, while a considerably smaller variation in drop resulting from the operation of other machines may be detrimental to weld quality.

6. *Rating* of a machine is an arbitrary designation indicating the kva at which a machine may be operated on the basis of a 50% duty cycle, which is more often the exception than the rule. The continuous rating of a machine is

$$\text{Continuous kva} = \text{Rating} \sqrt{0.5} = 0.707 \times \text{Rating}$$

or, in general, the demand at which a machine may be operated is

$$\text{Permissible demand} = \frac{\text{Rating} \sqrt{0.5}}{\sqrt{\text{duty cycle}}}$$

Substitution will show that, for example, a machine rated at 100 kva can be operated at 70.7 kva continuously at 224 kva at a 10% duty cycle or at 707 kva at 1% duty cycle. In practice, a machine will generally have a demand limited to three or four times its rating by the range of secondary voltages available.

Because of the short duration of their existence, the quantities 1, 3, 4 and 5 are not easily measured with conventional indicating instruments. Reasonable approximations are possible by using pointer stop ammeters and voltmeters, or more accurate results can be obtained with an oscillograph which is much more cumbersome to use. Unless the user is familiar with the limitations of his instruments, highly erroneous data may be collected. Even with an oscillograph it is not practical to determine the voltage variation. Means of obtaining this information are discussed in more detail elsewhere.

C. Design Criteria

Even given this information accurately, its interpretation and use in designing the distribution system or in determining the effect of the equipment on an existing system is difficult. Recognizing that in most cases there are a number of machines involved which may or may not be intermixed with other types of loads, there are two criteria involved in the design or evaluation of the system. These are: (1) the heating effect of the machines on the feeders, transformers, etc.; and (2) the voltage variation at the terminals of any machine resulting from the operation of other machines connected to the system.

Either of these may be the governing criterion, but it is generally the latter which is dominant. It is also the most difficult to determine. The following example will illustrate.

Suppose 20 machines were connected to a single-phase supply of 500-kva capacity, and that each was operating on a 5% duty cycle and drawing 100 kva while welding for 10 cycles. If the load center had a reasonably low impedance and the feeders were of adequate

BEST DISTRIBUTION
20 WELDERS OPERATING SUCCESSIVELY AT 5% DUTY CYCLE (10 CYCLES ON-190 CYCLES OFF) 100 KVA DEMAND EACH
2000
1500
1000
500
K.V.A. LOAD
BEST POSSIBLE MAX. DEMAND
BEST POSSIBLE EQUIVALENT CONTINUOUS LOAD-100 KVA
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 1 2
1-SEC.
2-SEC.
3-SEC.
TIME-CYCLES

Fig. 1 The best possible distribution of 20 machines operating at 5% duty cycle

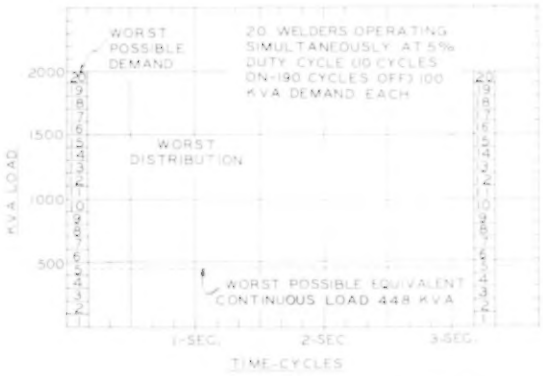


Fig. 2 The worst possible distribution of 20 machines operating at 5% duty cycle. Note that the demand is 20 times as great and the equivalent continuous load almost 5 times as great as the best possible condition shown in Fig. 1

size, this might result in a voltage drop at the point of connection to the feeders of 1.5%.

Let us consider two extreme operating conditions, neither of which is likely to occur but which must bracket the operating conditions. The first, illustrated in Fig. 1, is based on the premise that all of the machines will operate successively. Since for the purpose of this example we have selected a number of machines which is the reciprocal of the duty cycle, each of the resulting impulses of the same magnitude and duration will follow one directly after the other, and the consequent combined load is steady load of 100 kva. The system is operating at $\frac{1}{20}$ of its rated capacity, and the voltage drop at each machine (assuming that they are connected at the same point on the feeder) is 1.5%. The variation in the voltage drop is zero, since each weld is made with the same 1.5% drop.

Now let us consider the same machines operating under the worst condition which is that all machines fire simultaneously, as shown in Fig. 2. The combined demand is now 20 x 100 or 2000 kva. The over-all duty cycle is 5% and the equivalent continuous load is $2000 \sqrt{0.05} = 448$ kva. The voltage drop at each machine is 20 x 1.5% or 30%. The voltage variation is still zero since an identical number of machines operates each time.

Under the first premise, the system is quite adequate since it is operating well within its capacity and the voltage drop and voltage variation are satisfactory. Under the second premise, the system is operating at near capacity and the voltage drop is excessive which would cause difficulty with controls and relays. If this difficulty were overcome by using a separate control power source, the weld quality would be satisfactory provided that the machines *always* operated simultaneously as stipulated and assuming that the welders had sufficient capacity so that they could be set up under this condition of severe voltage drop. Of course it would be necessary to increase the open-circuit secondary voltage in order to circulate the same welding current which would increase the demand and further aggravate the conditions.

In spite of this drastic possibility, the system may still be adequate under normal random operating conditions depending upon the frequency with which one, two, three, etc. machines coincide. It is this consideration that will determine the frequency with which excessive voltage *variation* occurs, the limiting factor in this example. The most probable distribution and the corresponding equivalent load are shown in Fig. 3.

Weld Quality and Voltage Variation

At this point two questions arise: (1) what is a permissible voltage variation? and (2) how can this information be applied simply to the design or evaluation of a power system?

Any electrical equipment when connected to a power source will cause a voltage drop (or rise) at its terminals which is the vector sum of the drops in the feeders, transformers, high-voltage lines, sub-station and all other equipment in the circuit back to the source of the power. In most cases as one travels back along the system he gets to a place (usually the high-voltage lines feeding the sub-station) where the capacity is so large in comparison to the particular load involved, that it may be considered an infinite bus, having unlimited capacity at a constant voltage. Exceptions to this condition will occur in privately operated generating plants or when the utility distribution system is of low capacity or of relatively low voltage, say 2300 or 1160 v. While the voltage variations on such lines will seldom be sufficient to affect weld quality, light flicker is sometimes a serious problem. The amount of voltage variation which can be tolerated without objectionable flicker is dependent not only on the amount of the variation, but also on the rate at which it occurs. For example, on a 60-cycle system the voltage is zero 120 times per sec, but no flicker is noticeable because of the persistence of vision and the energy stored in the lights. On a 25-cycle system the same condition occurs 50 times per sec and flicker is noticeable, but one becomes ac-

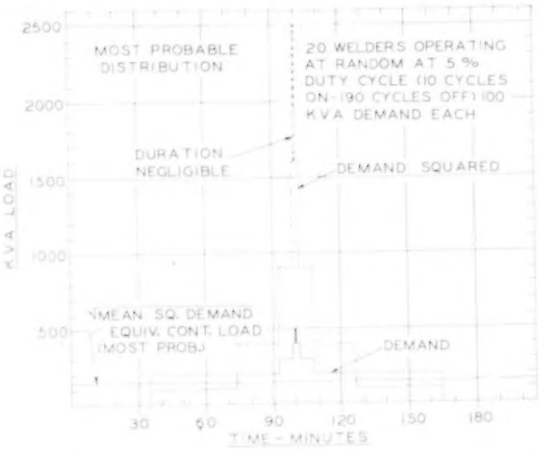


Fig. 3 The most probable distribution of 20 machines operating at 5% duty cycle. Time scale is purposely changed since this represents the average conditions over a large number of random operations. Note that the most probable conditions are much closer to the best conditions than the worst

customed to it. At rates of 5 or 10 times per sec variations of ½% are noticeable and variations of 3% or 1% are objectionable. At still lower rates larger variations can be tolerated. Curves of the borderline of visibility and the borderline of irritability are well established and readily available. The matter will not be pursued further here except to note that welders often fall in the range of most severity, and that when such a problem exists it can often be resolved by the use of corrective equipment, dummy loads, stored energy controls, etc.

The limitations on voltage variation are usually the effect upon weld quality itself. Variations in the voltage at the welder terminals will, of course, produce like variations in the welder current. Such a variation will produce a variation in the heat generated in the weld zone proportional to the square of the current, which means that in the relatively narrow range near normal operating conditions the amount of heat will be about twice that of the current and, hence, voltage variations. That is, a decrease of 10% will result in a current 90% of normal and heat 81% of normal. The variation of weld strength with current will vary from one material to another and will, to a degree, be dependent upon other settings such as weld force and weld time. It is a conservative assumption that for mild steel the strength will vary directly with the heat and, therefore, the variation in strength will be about twice that of the voltage. The user must set his own standards of weld quality. Obviously there will be a difference between aircraft requirements and those of an appliance manufacturer. Similarly, there could well be a difference in standards between one of twenty spots made individually in an assembly and something like a hinge bracket or brake pedal where one spot or one group of spots made simultaneously with one power impulse carried the entire physical load. For the purposes of this generalized discussion, one might assume that variations of 20% in strength would be a limit and that as a consequence the voltage variation should not exceed 10%. Keeping in mind that there are other sources of variation in weld quality such as electrode condition, force, cleanliness of material and fit of parts, it would be well to set the limit of voltage variation at 7% or perhaps 5% depending on the nature of the job. In a description of a distribution system in the November 1957 issue of THE WELDING JOURNAL, L. Fisher and R. W. Dailey set a limit of 15% once every 10,000 welds for their installation. While one in 10,000 is sufficiently conservative, allowing a 15% drop might be on the generous side considering the other sources of weld quality variations, the tendency of industrial plants to add load to existing facilities, and the usual steepness of the probability curve.

Having established a guide on which the user can base his own limits, we come to the main purpose of this discussion, which is to suggest a means of evaluating an existing system in terms of the two criteria set forth above.

Heating Effect

It has been pointed out that the thermal effect is not usually the limiting factor, but nonetheless one which must be checked. On existing systems measurement of the temperature rise of the various components is usually simple and quite satisfactory, if one keeps in mind the fact that the temperatures measured will usually not be the hot spots, and makes suitable allowances. If the equipment operates at the end of periods of heavy production within the limits of the nameplate rating, or at temperatures consistent with the type of insulation used, it is safe to assume that the thermal load is within bounds.

Because of the diversity of load which usually exists, where large numbers of machines are involved, recording ammeters, watt meters or spot check readings with indicating instruments will usually permit a determination of the equivalent continuous load. The user of such methods is cautioned to have a knowledge of his instruments' limitations.

Voltage Variation

Evaluation in terms of voltage variation is not quite so simple. The voltage drop produced by a particular machine can be measured with the intelligent application of pointer stop meters, oscilloscopes, etc., but this will not indicate how often the voltage variation caused by other machines is excessive. The distinction between voltage drop and voltage variation must be clearly understood. One machine producing a voltage drop at its own terminals of 10 or even 20% will consistently make good welds, other things remaining equal, but a variation of 10% produced by other pieces of equipment may result in a defective weld each time it occurs. Recording voltmeters will not respond quickly enough to give accurate indications of these variations. They can be observed on an oscilloscope or recorded by a light beam oscillograph, but continuous records of this type are costly to make and difficult and tedious to

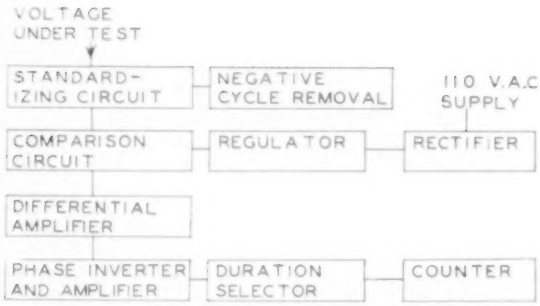


Fig. 4 Block diagram of the circuit functions of the voltage-drop counter

analyze. For example, if a machine were operating on 10-cycle weld time, a thousand impulses take up 10,000 cycles. Since there are 216,000 cycles in an hour these impulses would be observable only about 5% of the time at a rate of 1000 welds per hr, and could be easily missed without a continuous record.

It was this difficulty which led the authors to develop the voltage-drop counter (Fig. 4). It is an electronic instrument that can be set so that it will count (peak) voltage drops in excess of any preselected value, which exist for a preselected duration. The particular instrument made could be set for drops of 5, 10, 15 or 20%, and for durations of 5, 10, 15 or 20 cycles. It has a sensitivity of better than ½% so with minor modifications it could be built to count drops in increments of 1% or for other durations.* When connected to the source under test, the input voltage is set to a standard value to compensate for normal differences in system voltage. The amount and duration of the differences to be recorded are selected by means of two switches. The sensitivity control is set so that the instrument responds when a calibration button which artificially induces a drop of the selected amount is depressed, but does not respond when a second button causing ½% less drop is also depressed. The instrument is then left connected to the source and will count and record the number of times that the specified conditions occur. In order to determine the voltage variation, it is necessary to measure the drop at a particular machine, caused by that machine and set the counter to this amount plus the variation. In so far as the peak voltage is an indication of the line voltage, the counter will give the desired results.

Improvement of Inadequate Systems

While an adequate power-supply system is undoubtedly desirable, it must be recognized that such a condition is sometimes difficult or impossible to attain. A particularly critical operation may impose such stringent limitations that the cost is prohibitive. In some cases, managements are unable or unwilling to make the necessary investments. There is a number of means available to improve operation under these conditions and they are worthy of brief mention at this point.

1. Series Capacitors: Series capacitors may be used either to remove the reactive component of the welder current or to improve the regulation of the power system itself. Because of the change in the phase relationships which occur, the reduction in voltage-drop may be more or less than in proportion to the reduction in demand.

2. Frequency Conversion: By rectification or by rectification and inversion to a lower frequency, the reactive component of the welder can likewise be reduced. This system also lends itself to the distribution of load of a large single-circuit welder onto three phases.

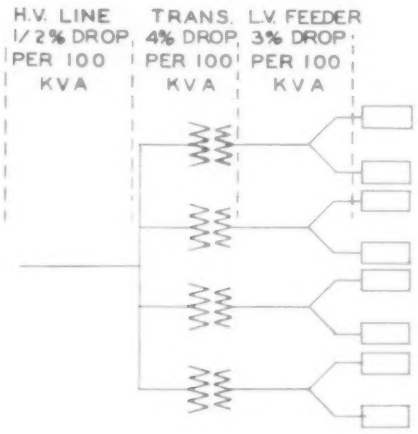
3. Energy Storage: A number of methods is available by means of which energy can be taken from the line at a steady rate, stored electrically or mechanically and delivered to the welder in impulses as required.

These systems are all practical and in general use in circumstances where justified. They, of course, add to the cost of a welder installation. In the case of large numbers of machines it is usually more economical to make the investment in the system rather than in individual welders. In addition to the above devices, which by one means or another reduces the demand of the welder, there are compensatory devices commercially available, which will, within a reasonable range, maintain welder current constant regardless of variations in line voltage or circuit impedance.

Within the distribution system itself, proper attention to detail will often permit considerable improvement without appreciable increase in cost. For example, feeders of identical wire size may have only half as much impedance if they are closely spaced in conduit rather than strung on spacers. Similarly the same amount of copper used in a larger number of smaller conductors, properly interleaved can result in a still greater reduction of impedance. Transformer impedances will vary from less than 2 to more than 5%; the lower impedance type having obvious advantages from a voltage drop standpoint. Many systems do not take full advantage of the diversity factor which results from the operation of a large number of welders on a single circuit. In our example of 20 welders operating at 5% duty cycle with a demand of 100 kva for 10 cycles, these machines might be connected in pairs to ten 100-kva load centers of, say, 1% impedance. The probability of two on the same circuit overlapping for half of their weld period is once in every 18 welds.† What might be a typical system of this type is shown in Fig. 5A, and with the resulting voltage variations and their rates of occurrence shown. If these machines were reconnected to a single load center of only ¾% the combined capacity of the ten 100-kva transformers as shown in Fig. 5B, (with feeders, etc. of proportionate size) a voltage variation of this severity only occurs once every 2500 welds. The voltage computations in these diagrams assume that the voltage drops add arithmetically. This is a

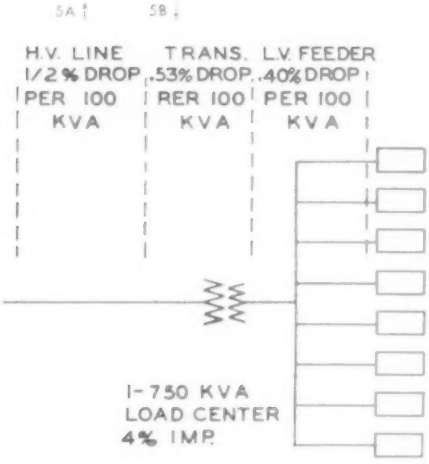
* As electronic devices go, the counter is relatively simple and can be built for about $200. A block diagram of its functions is shown in Fig. 4; and the authors will be pleased to furnish details of its construction to those who may be interested.

† See Appendix.



NO. OF MACH. FIRING SIMULTANEOUSLY	TOT. VOLTAGE DROP	VOLTAGE VARIATION & RATE OF OCCURANCE	
* 1	7.5	0 ONCE IN	1 WELDS
2	15	7.5	27
3	15.5	8.0	64
4	16.0	8.5	216
5	18.5	9.0	990
6	17.0	9.5	6000
7	17.5	10.0	45000
8	18.0	10.5	428000
9	18.5	11.0	5000000
10	19.0	11.5	NEG.
11	19.5	12.0	-
ETC.	-	-	-

* FOR MORE THAN 2 MACH. IT HAS BEEN ASSUMED THAT 2 MACH. CONNECTED TO THE SAME LOAD CENTER WILL BE ON SIMULTANEOUSLY SINCE THIS OCCURS SO FREQUENTLY



NO. OF MACH. FIRING SIMULTANEOUSLY	TOT. VOLTAGE DROP	VOLTAGE VARIATION & RATE OF OCCURANCE	
1	1.43	0	1 WELDS
2	2.86	1.43 ONCE IN	1.5
3	4.29	2.86	3.5
4	5.72	4.29	12
5	7.15	5.72	55
6	8.58	7.15	333
7	10.01	8.58	2500
8	11.44	10.01	23800
9	12.87	11.44	278000
10	14.30	12.87	4000000
11	-	14.30	NEG.
12	-	-	

Fig. 5 Diversity factor of a large number of machines can be used to improve voltage conditions. Note that the arrangement in B is considerably better from the standpoint of voltage variation than that of A, even though the load center capacity of B is only 750 kva while the combined capacity of the load centers in A is 1000 kva.

special case which would only occur when the power factors of the loads, transformers, feeders, etc. are equal. It is, however, a reasonable approximation and when in error it is on the conservative side.

It is customary, of course, to connect welders to three-phase circuits. An analysis of the voltage conditions which exist under unbalanced load conditions is quite complex, requiring the use of an analytical method known as symmetrical components, or access to a network analyzer. In most cases it is possible to treat the circuits as balanced three-phase circuits or even as isolated single-phase circuits, thereby greatly simplifying the calculations. The errors which result therefrom are again on the conservative side and provide a margin of safety.

Summary

From this discussion then the following conclusions may be drawn:

1. Because of the short duration of the impulses caused by resistance welders it is difficult to measure, with conventional instruments, the variables necessary for an analysis of the power system.

2. There are two criteria for the design of systems to

Table 1—Solution of Probability Formula (eq 2)

A	B	C	D	E	F	G	H	I	J
				$\frac{(N-1)!}{(N-1-S)!S!}$			Sum of first $N+S^2$ terms in column F	F divide terms in column H by $(a+b)^{N-S}$	Ratio of coincidence of S Mig 6 = A ÷ G
S	$N-1-S$	$(2a-2b+1)^{N-1-S}$	$(b-a+2b-1)^S$		Column C × D × E	S			
0									
1									
2									
3									
Etc.							Terms at top of this column are usually negligible		

* $0! = 1$ $1! = 1$
$2! = 2 \times 1 = 2$
$3! = 3 \times 2 \times 1 = 6$
$4! = 4 \times 3 \times 2 \times 1 = 24$, etc.

supply power for resistance welders. One is the heating effect of the machines on the system components and the other is the voltage variation which will result from the coincident operation of varying numbers of machines. While either may be the limiting factor, it is usually the latter which is dominant.

3. On a single machine, conventional instruments, intelligently selected and applied with a knowledge of their limitations, will divulge necessary data.

4. In order to evaluate a system to which a group of welders is connected, it is necessary either to calculate the probabilities of coincident occurrences, or to use an instrument which will indicate the frequency with which excessive voltage drops occur.

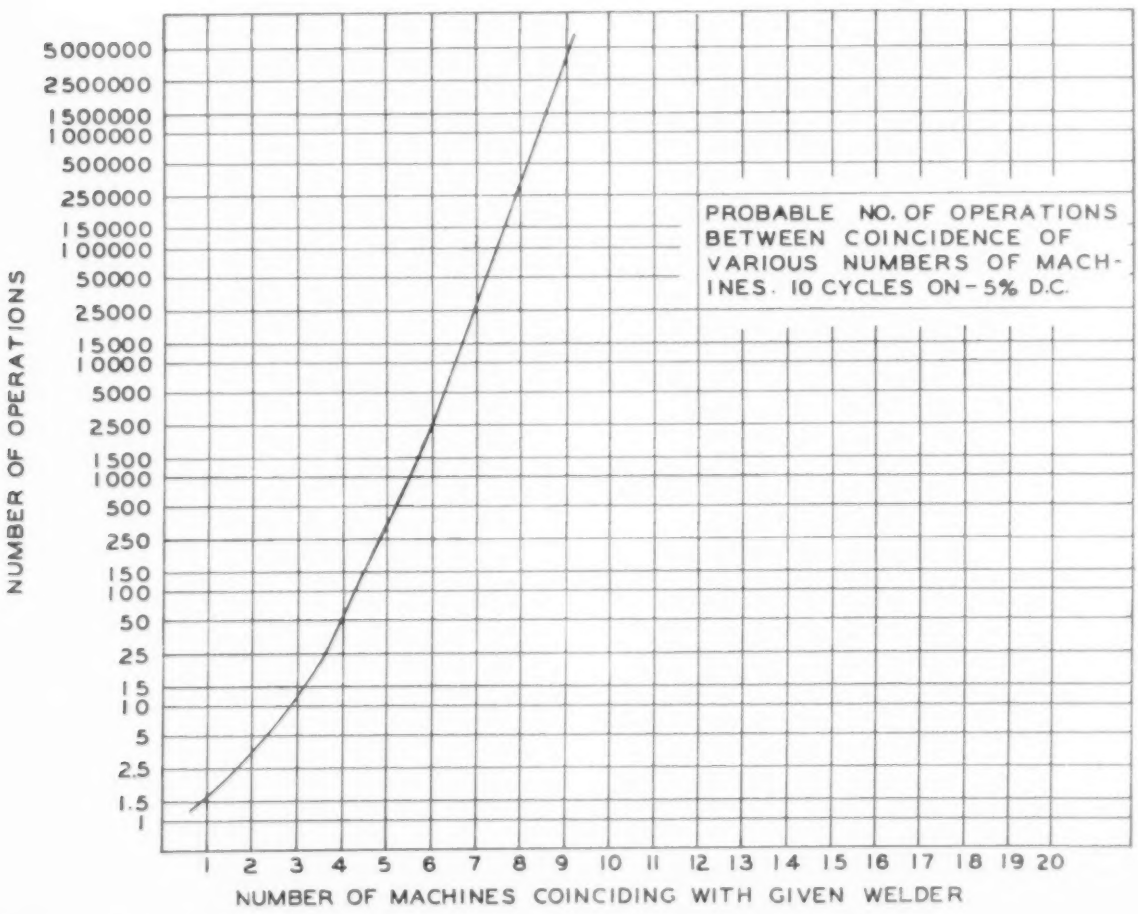


Fig. 6 Frequency of coincidence curve of the machine arrangement diagrammed in Fig. 5B

Table 2—Determination of Equivalent Continuous Current (eq 3)

A	B	C	D	E	F	G	H
							Column $B \times F \times G$ / $D \times E$
S	$S!$	$N - S$	$(N - S)!$	$S!$	d^S	$(1 - d)^{N-S}$	
0	0						
1	1						
2	4						
3	9						
4	Etc.						Lower terms in this column are usually negligible
Etc.							
			Multiply this sum by $N!$ (same as top no. in column D) take square root and multiply by demand of one Mach. This is equivalent continuous current required				Sum = ——— = Σ

* 0! = 1 1! = 1
2! = 2 × 1 = 2
3! = 3 × 2 × 1 = 6
4! = 4 × 3 × 2 × 1 = 24, etc.

5. The authors have developed a relatively simple electronic voltage-drop counter which will serve this purpose.

6. A number of corrective and compensatory devices are commercially available which will permit the installation of resistance welders on systems which would otherwise have excessive voltage variation.

7. Proper attention to the details of construction of the supply system can materially reduce the voltage variation which might otherwise exist.

Appendix

The probability p of any machine having at least k of its "on" cycles occur during any one of the equally likely intervals of a cycles representing the "on" time of a second machine, which is the probability of their overlapping for at least k cycles is

$$p = \frac{2a - 2k + 1}{a + b} \qquad (1)$$

It can be developed from the theories of probability that the probability P of at least s machines of a total of N coinciding for at least k cycles is

$$P = \frac{1}{(a+b)^{N-1}} \sum_{h=0}^{N-1-S'} \frac{(N-1)!}{(N-1-h)!\,h!} \times (2a - 2k + 1)^{N-1-h} \, (b - a + 2k - 1)^h \qquad (2)$$

While this appears to be a rather formidable formula it can be set up in tabular form as illustrated in Table 1 and thereby be reduced to a purely mechanical arithmetical computation.

The equivalent continuous current for such a group of machines is

$$I_e = I_s \sqrt{N! \sum_{S=0}^{N} \frac{S^S d^S (1-d)^{N-S}}{(N-S)!\,S!}} \qquad (3)$$

The radical part of this expression can easily be solved by using the tabular form shown in Table 2.

It should be noted that these expressions are resolved from the condition that the welders fire in integral cycles such as would result from the use of synchronous controls. Within the range of normal operation the differences resulting from the completely random firing permitted by nonsynchronous controls is so slight that the use of a different set of formulas is not justified.

Nomenclature

a = cycles duration of each weld ("on" time), presumed equal for all machines.
b = cycles between welds ("off" time), presumed equal for all machines.
h = variable of summation in equations.
N = number of machines under consideration.
S = number of machines coinciding for a period of at least k cycles.
$S' = S - 1$ = number of machines coinciding with a given one.
k = number of cycles of overlap considered detrimental at a given voltage drop.
P = probability that at least s machines will coincide for at least k cycles.
p = probability that any one machine will have k of its a "on" cycles occur during any preselected, equally likely period of a cycles.
I_e = equivalent continuous primary welder current (of a number of machines).
I_s = primary welding (demand) current of one machine.
d = duty cycle $a/(a + b)$.

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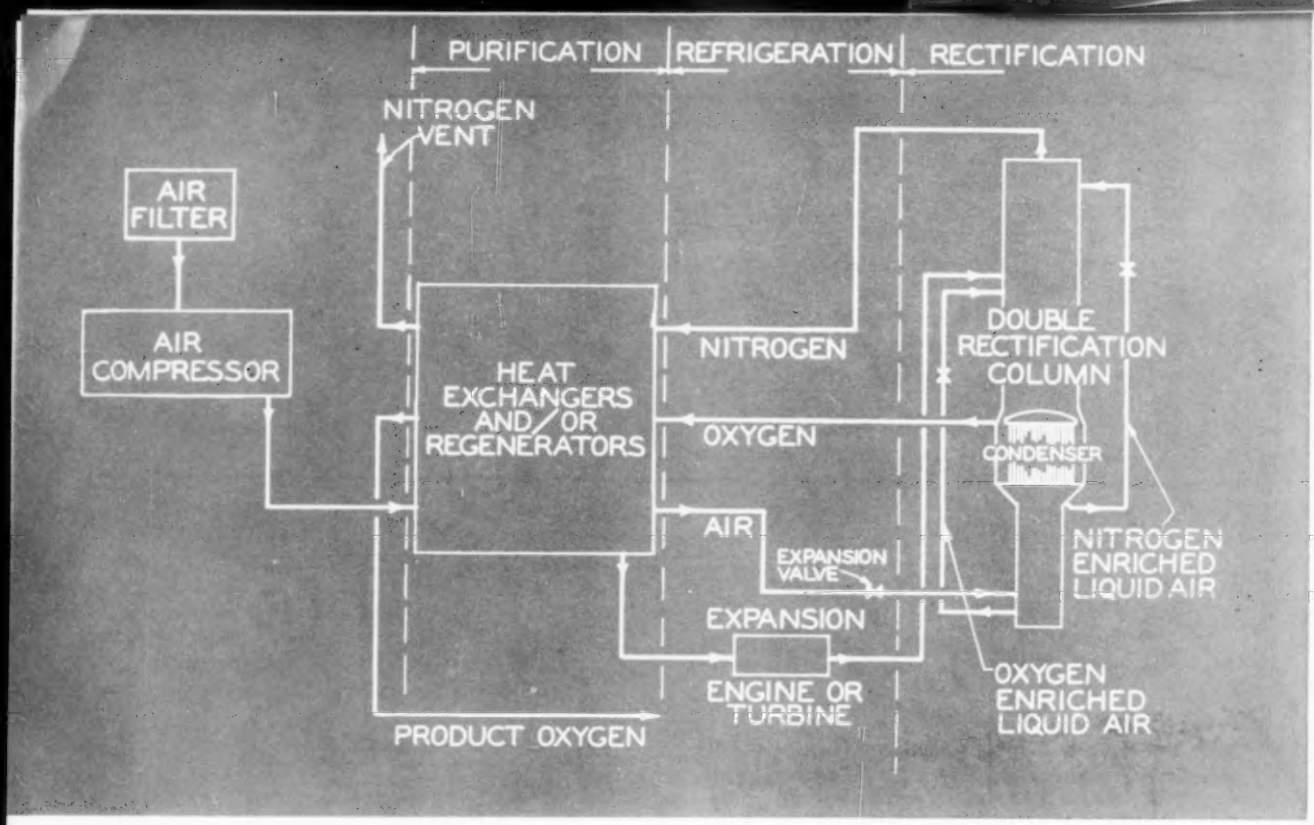


Fig. 1 Principles of oxygen production cycle

OXYGEN PRODUCTION

Purification, refrigeration and rectification are the fundamental steps involved in the production of high-purity oxygen (99.5% pure) by the liquefaction process

BY E. G. HICKLING AND A. E. HITTL

Oxygen is an abundant chemical that forms about 21% of the atmosphere around us. To separate it from the other chemicals that, combined with it, form the air we breathe is a complex process. Yet the result is vitally important to industry, medicine and explorers of space because oxygen is one of the primary tools of their trade. Generally, its production is achieved through the liquefaction and distillation of air. Other methods, principally of a chemical nature, can be employed, but are usually uneconomical when industrial volumes are required.

There are several different ways to achieve high-purity oxygen (99.5% pure) by the liquefaction process. Three steps, however, are fundamental. They are purification, refrigeration and rectification. Purification is self-explanatory. It means the removal of foreign matter from the air. Refrigeration means something more than the word as we commonly think of it, for in oxygen production it means cooling the air until it becomes a liquid. At normal pressures this will not happen until the air reaches the exceptionally low temperature of -300° F. Rectification means separation by repeated distillation of the liquid-air components of oxygen from the other gases that are combined with it in the atmosphere around us.

Combined, these three operations make oxygen from the air, but each step is a detailed process in itself. Several different methods can be used in each case and, in the actual production of oxygen, any number of combinations is used.

E. G. Hickling is vice-president and A. E. Hittl is assistant manager of engineering of Linde Company, Division of Union Carbide Corp.

Purification

The first step is purification. The atmosphere is not only a mixture of various elements such as oxygen, nitrogen, argon and rare gases, but it holds dirt, water vapor, carbon dioxide and certain combustible hydrocarbons as well. These are the impurities to be removed in the first phase. Purification can be accomplished in three ways—a chemical method, a mechanical method and a combination of both. To remove the impurities chemically, a substance is used to produce a removal reaction. For example, sodium-hydroxide solution will remove carbon dioxide from the air. Other chemicals have a similar effect on the other impurities.

Mechanical purification can be realized through traps, refrigerated heat exchangers, reversing heat exchangers, regenerators, absorbents and various types of filters. This method is supplemented by chemical purification where necessary.

Often volumes in excess of a million cu ft of air per hour must be purified. In such cases, impurities present, only to the extent of a few parts per million, can attain important proportions. In processing large volumes of air, chemical removal of impurities alone is too expensive; consequently, mechanical methods are more commonly used.

Refrigeration

Fundamentally, all plants cool the incoming air by transferring cold from the cooler outgoing plant products in a heat exchanger or regenerator. Also, as a first step in many plants, heat exchange is employed between the incoming air and a refrigerant. After purification and this preliminary cooling, the clean air is liquefied, or partially liquefied, by further cooling which can be accomplished in two different ways.

Using the Joule-Thompson effect is one way to lower the temperature of air. This method removes heat by letting gas under pressure expand to a lower pressure through a throttle-valve or nozzle. Since the temperature is lowered due to the increase in volume, the released air is cooled considerably.

The other way to remove heat from air is to make it do work. This is accomplished by using the air to drive a reciprocating expansion engine or turbine. The result is transformation of heat into mechanical energy which cools the air.

Rectification

When the temperature of the air has been lowered sufficiently to liquefy it, the third phase can take place: rectification, or distillation, which produces desired high-purity liquid oxygen. As mentioned earlier, rectification is the separation, or fractionation of air into its various parts. What actually takes place is the distillation of air, the components of which react to varying temperatures. This too can be accomplished in different ways—all of which revolve about a basic unit known as a "separation column." These columns consist of a series of trays enclosed in a cylindrical casing. As it flows down the column, the partially-liquefied air goes over the levels of trays, and the various lower-boiling-point constituents are boiled off (particularly nitrogen). These work their way toward the top of the column. The liquid that continues to flow downward over the trays becomes richer and richer in the higher boiling-point constituent—in this case, oxygen.

One of the most common separation units is the double rectification column. The physical principle for operation of the double column is that increased pressure on a liquid increases its boiling point. Inside the unit two columns maintained at different operating pressures are separated by a "condenser." The partially liquefied air enters the high-pressure column first where—because it is under a higher pressure—it liquefies at a warmer temperature than in the low-pressure part of the unit. Because of the different temperatures required to liquefy air under varying pressures, the condenser is able to affect both columns favorably. Gas rising from the high-pressure column goes into the condenser and is cooled by the colder liquid in the low-pressure column that surrounds the condenser tubes. It condenses and begins to work its way to the bottom of the high-pressure column, becoming richer and richer in pure oxygen as it drops across the trays. At the same time, the nitrogen-laden gas rising into the condenser from the high-pressure column, being warmer than the liquid at the bottom of the low-pressure column (the other side of the condenser), serves to produce boiling in the liquid at the bottom of the low-pressure column.

Liquid in the high-pressure column is drawn off and injected into the low-pressure column through two different lines, one carrying nitrogen-enriched liquid from the top of the column—the other carrying oxygen-enriched liquid from the bottom of the column. The exact point for injecting them into the low-pressure column depends on specific plant design. The liquid at the bottom of the low-pressure column is high-purity oxygen. It can be removed from the plant as a liquid, or as a gas after passing through a heat exchanger against the incoming air.

To explain the oxygen production operation better, a body of air should be followed through the entire oxygen-producing cycle. As shown in Fig. 1, air enters the plant through a filter and is compressed before it enters the purification stage. This compression serves to move the air through the various oxygen-producing phases. The heat, generated by the compression, is easily removed by heat exchange with water. The air then goes through purification by heat exchangers, or regenerators, or both, and is considerably cooled before it enters the next refrigeration stage. Here either the Joule-Thompson effect, the expansion engine method or both can be used to cool the air to partial liquefaction. Now it enters the double rectification column where the final liquefaction and boiling off of nitrogen take place. The result is liquid oxygen, better than 99.5% pure, ready to be used, transported or stored in liquid or gaseous form, according to prevailing requirements and plant design.

COMPARATIVE PROPERTIES OF ELECTRODES FOR ARC WELDING AUSTENITIC MANGANESE STEELS

Paper by W. L. Lutes and H. F. Reid, Jr. appeared in August 1956 issue of Welding Journal, 35, 776 783

DISCUSSION BY H. J. CHAPIN

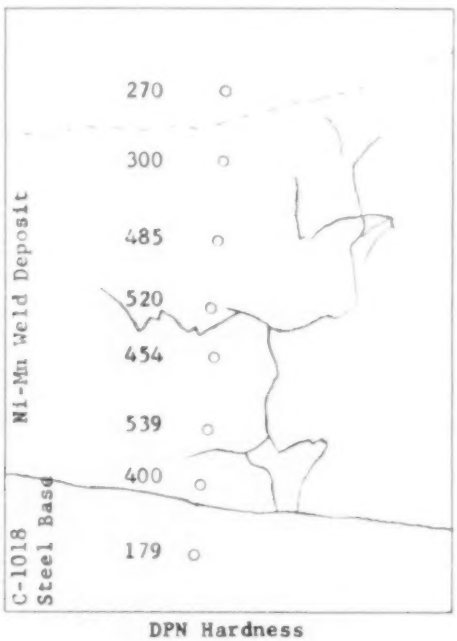
Technical papers that present data with the intent of comparing various materials for a particular purpose are always welcome. The present report by Messrs. Lutes and Reid is no exception. However, it is believed that it would have been of greater service to industry if the analyses of the various Hadfield manganese-steel welds had been more nearly of the same composition except for the basic differences in their chemistry. It is unfortunate that the carbon in the deposits for both of the groups of the molymanganese type welds was below the recommended ranges in the AWS Specification A5.13-56T, ASTM Designation A399-56T, with the manganese also on the low side. In addition, there was a large spread in chemistry in all of the welds in groups 1 and 2.

For reference, the limits in composition for manganese steel E FeMn-A and B in the above specifications are shown in Table 1.

In order for the characteristically tough properties of manganese steel to be developed, the structure must be austenite with a composition balanced to allow

H. J. Chapin is associated with American Brake Shoe Company, Mahwah, N. J.

D-1 The martensitic structure resulting from the dilution of the austenitic alloy with mild steel may be observed. The crack suggests that the area is highly stressed. This appeared earlier as Fig. 1G in Reference 1



D-2 This is traced from D-1 showing the outlines of the main features in the structure together with the location of the hardness readings taken across the area

Fig. D Microstructure and hardness traverse of weld of nickel-manganese steel on a base of C-1018 steel

Table 1—Analysis Specifications for Austenitic-Manganese-Steel Welding Rods

AWS A5.13-56T ASTM A399-56T

AWS-ASTM classification	C%	Mn%	Si%	Ni%	Cr%	Mo%	P% Max	Fe%	Other elements, Max %
E FeMn-A bare	0.55	12.5	0.4	2.75	0.50		0.07	Remainder	1.0
	0.90	16.0	1.3	5.0					
E FeMn-A covered	0.5	11.0	0.3	2.75	0.50		0.07	Remainder	1.0
	0.9	16.0	1.3	min.					
E FeMn-B bare	0.65	12.5	0.4	..	0.50	0.6	0.07	Remainder	1.0
	0.90	16.0	1.3			1.4			
E FeMn-B covered	0.5	11.0	0.3	..	0.50	0.6	0.07	Remainder	1.0
	0.9	16.0	1.3			1.4			

Table 2—Effect of Chemistry Levels on the Mechanical Properties of Austenitic Manganese Steel

Specimens were from 1-in. diam sound cast bars, heat treated at 1900° F-2 hr-water quenched, and then machined and ground to 0.505 in. diam 2-in. gage length

Bar No.	C%	Mn%	Si%	Mo%
A	0.47	11.0	1.5	2.0
B	0.74	13.9	0.5	1.9

Bar	Yield strength, psi*	Tensile strength, psi	Elongation, %	Reduction in area, %
A	45,800	96,750	11.5†	12.6
B	57,000	125,750	51.0	33.0

* Yield Strength at 0.2% offset determined by extensometer.

† The gage length was strongly magnetic after test.

Table 3—Effect of Pouring Temperature and Grain Size on the Mechanical Properties of Nickel and Molybdenum Grades of Austenitic Manganese Steels

1-in. diam sound cast bars heat treated 1900° F-2 hr-water quenched, and machined and ground to 0.505-in. diam gage-length tensile specimens

Bar	C%	Mn%	Si%	Mo%	Ni%
C	0.90	13.6	0.5	1.0	
D	0.91	13.3	0.5		3.4

Bar	Pouring temperature	Yield strength, psi*	Tensile strength, psi	Elongation, %	Reduction in area, %
C	hot (coarse grain)	52,600	106,250	39.0	33.4
C	cold (small grain)	55,700	134,250	58.5	38.2
D	hot (coarse grain)	44,600	103,000	45.5	35.6
D	cold (small grain)	46,000	127,800	61.5	40.6

* Yield Strength at 0.2% offset determined by extensometer on Bars C, and by SR-4 gages on Bars D.

Table 4—Tensile Properties, Analyses and Statistical Evaluation of All-Weld-Metal Specimens Machined and Ground from Butt Welds in 1-in Thick Cast Austenitic Molybdenum-Manganese Blocks. Specimens are in the As-Welded Condition

Specimen	C%	Mn%	Si%	Mo%
X-1277	0.65	13.2	0.4	1.8
X-1761	0.47	14.9	0.4	1.4
X-1231	0.58	15.7	0.3	1.3
X-1206	0.52	14.9	0.4	1.2

Specimen	Yield strength, psi*	Tensile strength, psi	Elongation, %	Reduction in area, %
X-1277	63,480	103,900	20.0	36.0
X-1761	67,500	102,500	18.5	24.9
X-1231	62,400	101,500	23.5	29.8
X-1206	66,840	106,500	19.5	26.1
n =	4	4	4	4
$\bar{x}$ =	65,055	103,600	20.375	29.200
σ =	2,162	1,879	1.88	4.32
$S\bar{x}$ =	1,248	1,085	1.09	2.49
2σ =	4,324	3,758	3.76	8.64
$2S\bar{x}$ =	2,496	2,169	2.17	4.99
P =	<0.001	<0.001	<0.001	0.01-0.001

* Yield strength at 0.2% offset determined by extensometer except X-1761 which was read from the dial.

n = Number of items compared.

$\bar{x}$ = Average value.

σ = Standard deviation. In a larger sample, 66% of the readings should be within $\bar{x} \pm \sigma$.

$S\bar{x}$ = Standard error of the mean. There is 66% probability that the true mean is within $\bar{x} \pm S\bar{x}$.

P = Probability that the mean of random samples would lie outside the range of the standard error. The lower the value of P, the greater is the probability that the mean is a significant value.

NOTE: with 2σ and $2S\bar{x}$, the probabilities are raised to 95%.

considerable plastic flow before much transformation occurs on the planes of slip. When either carbon, manganese or both are low without compensation by other elements, the structure tends to transform more rapidly (as shown by the appearance of magnetism) while exhibiting reduced tensile and toughness properties. On the other hand, more rapid work hardening with a greater resistance to flow under repeated impact loading will be observed. Hence, when alloys are being compared for the differences produced by nickel or molybdenum, the results can be obscured if the supporting chemistry and other factors are capable of affecting the properties more strongly than the featured variables. The data in Tables 2 and 3 from sound one-inch diameter cast bars illustrate this. It is good practice to use sound cast bars when discussing the properties of various grades of manganese steel. Variations in welding procedure, interpass temperatures, degrees of reheating and other variables as well as incidental chemistry can easily mask the basic

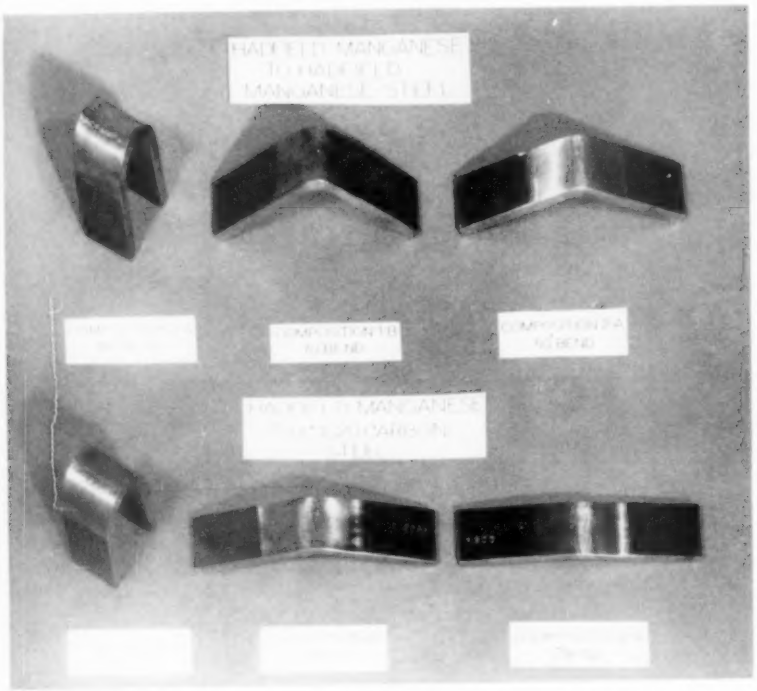


Fig. C-1 Results of guided-bend tests made of specimens welded without the use of stainless-steel electrodes

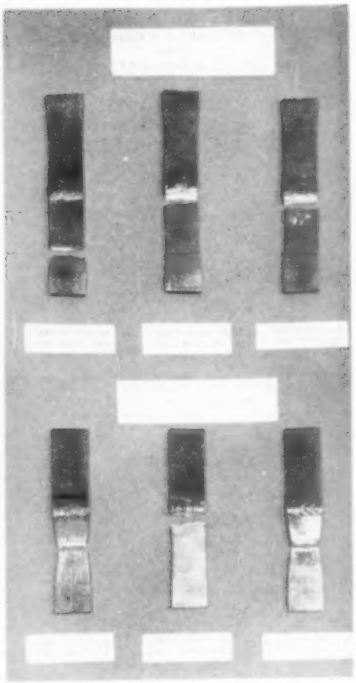


Fig. C-2 Specimens welded under same conditions as those in Fig. C-1 but tested in tension

information being sought. We feel confident that the data in the present paper are likewise affected. The disparity in results between the various rods tested and reported is not the true difference between the two basic compositions as can be observed below. It is not to be implied that the properties of castings can be used for those of welds, but the trends in performance established with castings of the same compositions as the welds can be considered valid.

Table 3 also presents comparative figures on nickel-manganese and moly-manganese specimens. The slight differences noted between the two grades other than in yield strength are without significance. The merits of the two compositions are discussed more fully in an earlier paper,[1] in which the moly-manganese grade is considered slightly superior on the basis of its higher yield strength.

Test results and statistical analysis from tensile specimens machined entirely from manganese-steel butt welds used to join castings of the same composition are shown in Table 4. The recommended manganese-steel procedure of cooling below 400° F between passes was followed.

With respect to Charpy impact tests, values given in the ASM Handbook[2] indicate nothing to be feared in low-temperature service of austenitic manganese steel.

It has long been recognized that it is unwise to weld austenitic-manganese steel to carbon and low-alloy steels with manganese rods because of the crack-sensitive martensitic zone produced by the intermingling of the two compositions. A photomicrograph illustrating this appears in Fig. D-1. A hardness traverse made with a diamond-pyramid indentor and 25-g load through this same area is presented in Fig. D-2. A band may be observed that will be sensitive to service stresses, and whose hardness will be higher or lower depending on the compositions of the alloys being joined. In the paper under discussion, the welds for the tensile and Charpy specimens were protected from base-metal effects by two layers of the welding alloy in question, but the crack tests were not given this preparation. It would appear therefore that the cracking tests are not truly evaluating the alloys, but rather a lower strength, higher hardness product of dilution. Perhaps cracks will not appear in all cases, but the zone of higher hardness will still be there. The authors' data indicate that moly-manganese welds are crack sensitive whereas this is unlikely to stem from molybdenum. With another type of weld-cracking test described in reference,[3] crack-free welds were obtained in a variety of manganese-steel compositions including the nickel and molybdenum grades. These comments of course do not detract from the excellent performance of steel 1A.

We should like to urge in closing this discussion that other statistical values besides the average,

such as number of tests, standard deviations and standard errors of the mean as shown in Table 4 be included for the data reported as they would assist in clarifying their interpretation.

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AUTHORS' CLOSURE

Mr. Chapin's comments and discussion of this paper fall into the following four main categories:

1. Lack of control of the chemical analysis of the various materials listed under Groups 1 and 2.
2. The relative merits of cast vs. welded test specimens.
3. Validity of the armor-welding crack test.
4. Lack of a statistical presentation of the data.

It appears to the authors that, in general, these points-of-issue arise from differences in approach to the subject. Mr. Chapin and his associates are concerned primarily with fundamental research and its relation to the problems of making, fabricating, and welding austenitic-manganese steels. Their contributions to the literature, in general, and welding technology, specifically, stand as a tribute to the success of their operations. On the other hand, this paper was designed as a practical approach to the problems of welding manganese steel and to acquaint the user with the widely divergent properties of commercial materials recommended for what, at first glance, appears to be the same application. Of necessity, the methods and tests for such a presentation differ from those used in a fundamental study.

Control of weld-metal composition was not the intent of the paper as outlined in the introductory paragraphs. The five specific electrodes composing Groups 1 and 2 were the commercial product of four major electrode manufacturers. They, presumably, represented material which could be purchased under the specific brand label in any of the forty-eight states. It only could be assumed that the weld-metal compositions in each case represented the specific company's opinion of what constituted the best nickel- or molybdenum-manganese analysis. The rather wide divergence in weld-metal composition and properties was readily apparent, suggesting a lack of agreement among the various manufacturers. The authors hoped that the data presented would stimulate additional activity designed to improve further and to standardize at the highest possible levels the properties of nickel- and molybdenum-modified austenitic manganese weld metals.

The question of cast versus all-weld-metal test specimens is another example of the difference in approach between fundamental and application research. Both types of specimens have certain inherent limitations which are readily apparent. For a comparative presentation of this type, the authors felt that all-weld-metal specimens provided the most direct approach.

As pointed out in the text, crack resistance is an extremely difficult property to measure and evaluate, as evidenced by the wide number of different crack tests employed by various investigators. The armor-weld crack test employed in this study combined simplicity, speed, reproducibility and sensitivity. The authors were aware both of the accepted danger of welding austenitic-manganese steels to carbon steel and the development of a hard crack-sensitive martensitic zone at the interfaces. It was of interest that all cracking in this test occurred through the center line of the bead rather than at the edges. Metallographic examination of austenitic manganese to carbon-steel welds showed marked differences in width of such hardness bands. It was felt that differences in relative crack sensitivity or resistance reflected these variations in width.

Experience has demonstrated that, for many applications, Composition 1A may be used successfully to join carbon to manganese steel or manganese steel to manganese steel without the use of stainless-steel electrodes. Success of the unconventional combination of properties of this composition is illustrated by the results of a series of guided bend-tests, Fig. C-1, made of specimens welded without the use of stainless-steel electrodes. Double-V butt joints welded under the same simplified welding conditions fractured under tension load as shown in Fig. C-2. Composition 2A proved borderline when used to join carbon steel to manganese steel. Failure under load in the carbon-steel plate material was accompanied by tearing at weld-carbon steel interface.

The unconventional use of Composition 1A as outlined was verified by extensive field trials prior to release of these data and has been confirmed by additional tests in recent months.

It was not the intent of the original text to suggest that the apparent crack sensitivity of the molybdenum-manganese weld metals, Compositions 2A and 2B, was the direct result of the addition of molybdenum, per se. Crack sensitivity of any of the nickel-manganese or molybdenum-manganese weld metals was the net result of alloy balance rather than the effect of a single alloying element.

As for the fourth point, the authors examined and rejected a statistical presentation of data. In their opinion, such an approach would add to the complexity of a relatively straight-forward paper without an attendant increase in usefulness or readability.

COMPOSITE ARC-WELDED STEEL CRANKSHAFT DEVISED FOR PORTABLE GANGSAW

BY LEIGHTON W. JOHNSON

Two basic design problems had be to assimilated in the development of a 12-ton portable 24- x 26-in. gangsaw. They were: (1) how to realize a completely self-contained unit, including power, that would not exceed highway laws for weight or width; (2) how to reduce vibration so that the equipment could be operated in the woods anchored to the frame of a low-bed trailer. The job was accomplished, with the major assistance of arc-welded steel components. Details may be of value to designers of similar heavy-duty equipment to which portability would lend an advantage (see Figs. 1 and 2).

The stationary gangsaw is a familiar tool in the sawmill industry, having been imported originally from Germany and Sweden. It derives its name from the fact that it is a multiple-blade saw, with the blades moving up and down at a speed of about 300 strokes per min as a log is passed through the machine by feed rollers. The blades are spaced to cut 1- or 2-in. thickness, being held firmly in a steel frame or sash.

Diameter of the log that can be cut depends upon the dimensions of the sash. Thus a 24- x 26-in. gangmill can saw 24-in. diam logs with 2 in. to spare. There is no limit to the length of log that can be handled. Short or long lumber can be cut readily, being fed continuously through the machine.

The sash slides up and down in vertical guides, with reciprocating motion imparted to it by either a crankshaft or crankpins on heavy-driving wheels. Since the sash, with its multiple blades and saw hangers, constitutes a considerable weight, it is difficult to balance out the vertical forces due to reciprocation. Such forces can be very destructive and are offset by three methods: (1) limited maximum rpm; (2) counterbalance weights on the flywheels; and (3) a heavy frame and base to absorb vertical forces. The latter technique usually is employed but is not adaptable to a portable design.

For the desired portability, the gangsaw had to be positioned on a low-bed semi-trailer. This required a suitable frame to support the sawing mechanism.

Leighton W. Johnson is Chief Engineer at Gunderson Bros. Engineering Corp., Portland, Ore.

Based on a prize-winning paper submitted in the recent Machine Design Competition sponsored by The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio.

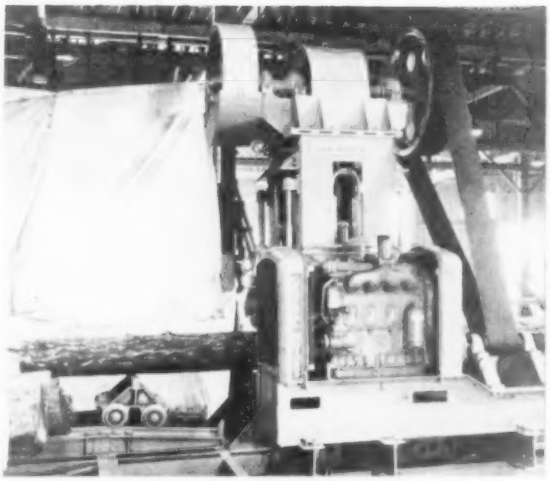

Fig. 1 Illustration of the gangsaw

From the illustration of the gangsaw (Fig. 1), it will be noted that flywheels and crankshaft are on top of the frame, in direct contrast to all foreign-made gangmills which have flywheels in the base. Conventional design could not be followed because it was necessary to mount the diesel engine on the trailer frame alongside the machine base to come within the 8-ft highway width limit.

The saw frame comprises three weldments—right and left hand side plates and the cap. Use of weldments not only improved the economic feasibility of the design but also played an important part in meeting the design criteria mentioned at the outset of this discussion.

Rear-axle weight of the semi-trailer supporting the saw and engine grossed 23,440 lb by actual scale measurement. This permitted the use of two 13,000-lb capacity axles on the rear of a conventional semi-trailer frame. With weight and width falling inside state highway regulations, the portable unit has been towed successfully over highways in most of the western states of the U. S.

No other component was as important to the success of the design as the crankshaft (Fig. 2). To assure sufficient saw stroke, a 9½-in. throw was necessary. Three alternatives were considered in material and method of

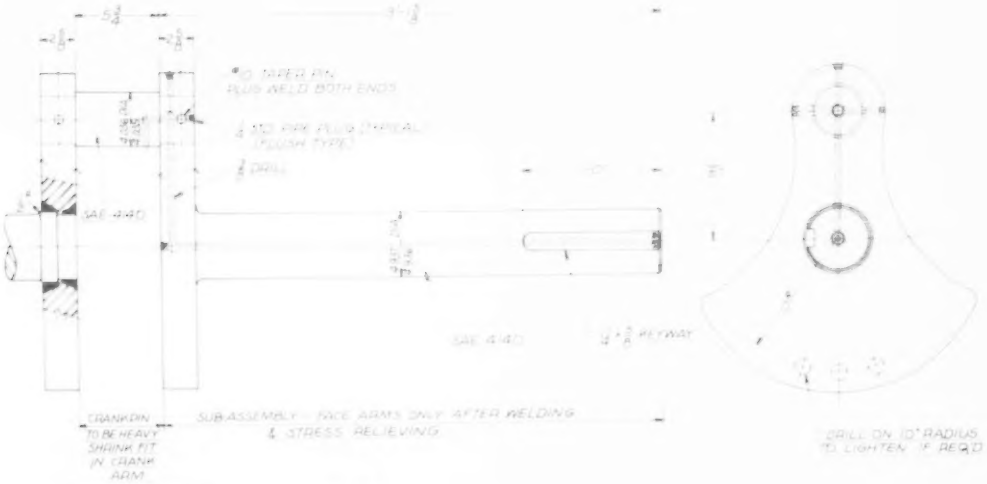
SAE 4140
SAE 4140
SUB-ASSEMBLY — FACE ARMS ONLY AFTER WELDING & STRESS RELIEVING
CRANKPIN TO BE HEAVY SHRINK FIT IN CRANK ARM
DRILL ON ID RADIUS TO LIGHTEN IF REQ'D

Fig. 2 Drawing of welded crankshaft

manufacture—a one-piece or two-piece steel forging, a steel casting and a composite weldment. The latter finally was chosen, after thorough analysis of the forces acting on the crankpin.

These forces are of different character than those encountered in a gas engine or air compressor. Only the inertial forces of the reciprocating masses and the centrifugal forces of the revolving parts of the connecting rod are involved, with no additional load due to cylinder pressure. Total vertical forces from reciprocating masses were calculated to be 28,920 lb, and centrifugal force 13,000 lb.

After some study and testing it was decided that centrifugal loads could be balanced out, leaving the load of the reciprocating masses as an unbalanced force. By the use of a weldment, it was relatively simple to balance out the revolving centrifugal forces. This was done by oxygen cutting steel plate $2^{3}/_{4}$ in. thick to form both the crankshaft arms and the required counterbalance.

As indicated in the accompanying Fig. 2, the crankpin has diameter of 4 in. and length of $5^{3}/_{4}$ in., resulting in a bearing pressure of 1256 psi. Since this is relatively high, another advantage of the welded construction becomes apparent. The crankpin could be hardened, chrome plated and shrunk fit into the crankplate arms, an impossibility had the entire shaft been a steel casting.

Bending moment at the crankpin center was sufficiently high as to call for an alloy-steel heat-treated crankpin. This was readily possible with the composite welded design: so, SAE 4140 steel was selected, heat treated to 300–350 Brinell and giving a safety factor of over 5.

Analysis of the stresses in the crank webs indicated that they could be made of mild steel and fastened to the shaft by welding. Shear stress at the weld point was only 11,200 psi. The complete weldment thus has mild-steel crank webs, SAE 4140 for the 5-in. diam shaft and for the chrome-plated crankpin. Finished weight is 811 lb.

In addition to somewhat lower cost, advantages of the composite welded crankshaft over a casting include the following:

1. Machining of a cast steel part—or even a forging, for that matter—would have been difficult, since few shops are equipped to machine or grind the crankpins of a $9^{1}/_{2}$-in. throw shaft.

2. Chrome plating of the crankpin on a cast shaft would have proved troublesome. In the welded unit, the pin is hardened, chrome plated and ground before pressing into the web plates.

3. Web plates being of heavy mild-steel plate, it was possible to incorporate the counterbalances into the design without expensive pattern requirements.

4. The shaft itself is machined from forged alloy-steel bar stock, thus assuring uniform quality as well as strength.

Other weldments in the gangsaw include the crosshead at the top of the sash, which is of T-1 low-alloy steel; driving flywheel and damper flywheel; frame side plates and frame cap.

The damper flywheel is of unusual construction, comprising a rim of $2^{1}/_{2}$- × 15-in. cross section (the inertia mass), connected to a solid center section by flat bar springs. The latter are of $^{5}/_{16}$- × $2^{1}/_{2}$-in. stainless steel, and allow the rim to move slightly under vibration torque.

PRINCIPLES OF BRAZE WELDING

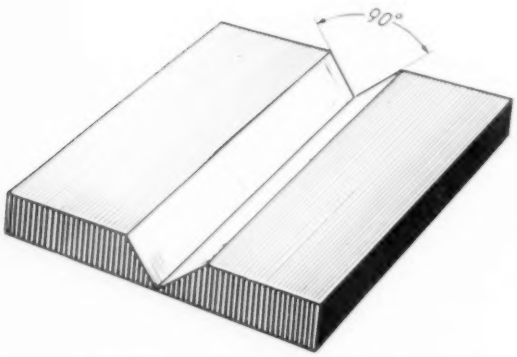

Fig. 1 For metal over $\frac{1}{8}$ in. thick, bevel to make an angle of about 90 deg. A coarse file can be used. For heavy sections of cast iron, a grinder wheel will be needed—for steel castings, a cutting torch or gouging nozzle

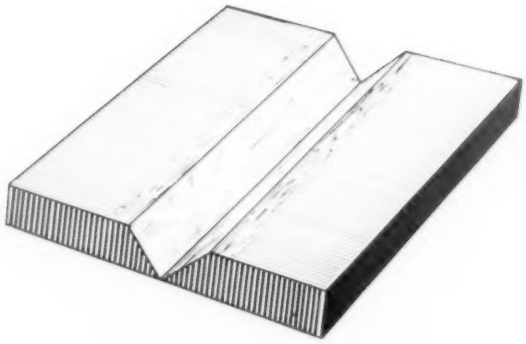

Fig. 2 Thorough cleaning is one of the secrets of a good weld. Remove all oil, grease, scale, rust or oxide from the beveled edges. Clean the top surface $\frac{1}{2}$ in. back from the edges. Use a grinder, stiff wire brush, file, emery cloth or steel wool

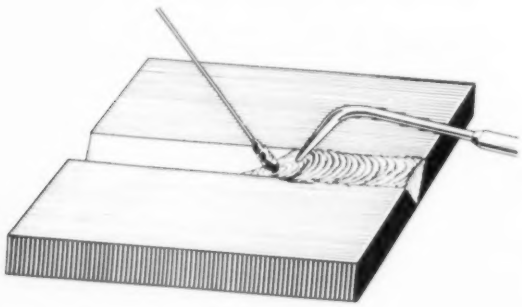

Fig. 3 The beveled surfaces must also be cleaned by using a liberal amount of flux. Add the flux by dipping the end of the hot rod into the flux can. A flux-coated bronze rod helps, because you are sure of getting exactly the right amount

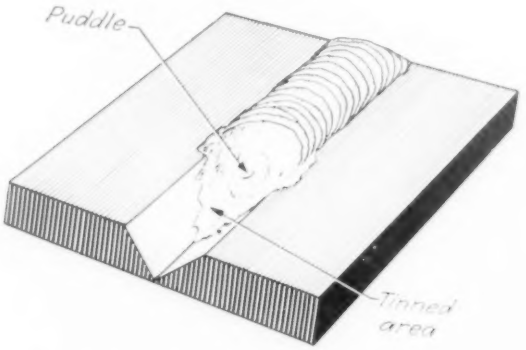

Fig. 4 Tin the surface ahead of the main rod deposit when the metal is at the right temperature and thoroughly clean. If the metal is not hot enough, the bronze rod will form into drops. If the metal is too hot, the bronze rod will boil and form into little balls

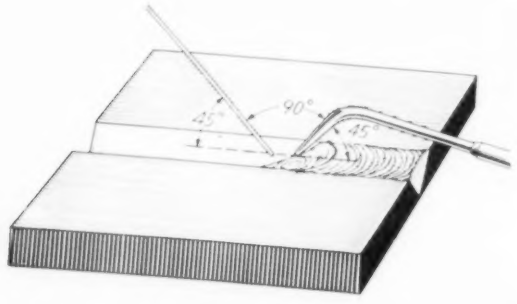

Fig. 5 Position of blowpipe and rod is another secret for making good braze welds. For a weld in the flat position, hold both rod and torch at an angle of about 45 deg to the workpiece

Fig. 6 Adjust the flame until there is a slight excess of oxygen. The oxidizing flame has a bluish outer envelope and a shorter inner cone than the neutral flame. There is no secondary flame or feather

Based on a story by the Linde Company, New York, N. Y.

OXYGEN CUTTING SPEEDS JET BRAKE ROTOR PRODUCTION

Oxygen shape cutting is now the key to faster production of brake rotors for jet aircraft by Alpha Industries, Logansport, Ind. But before Alpha standardized on oxygen cutting, a tough production problem had to be licked: could 18 slots, only $\frac{1}{16}$ in. wide, be accurately oxygen cut in a steel blank $\frac{7}{16}$ in. thick?

An entirely new production method to replace machine tool cutting was worked out. Results? A better rotor is produced faster. While formerly the rotor was fabricated in six segments, it is now produced in one piece, thus increasing its service life and simplifying the production cycle.

Development of the new production method hinged on the ability of a cutting machine and twin torches to make close-tolerance slots $\frac{1}{16}$ in. wide in the steel blank. Here's the production sequence worked out:

Two rotor profiles are simultaneously oxygen-cut by a cutting machine from the $\frac{7}{16}$-in. thick steel blank (Fig. 1). The machine mounts twin cutting torches side by side on a special 90-deg adaptor bracket. The torches are guided by magnetic tracing equipment to assure maximum accuracy along the 18-in. inner and 42-in. outer circumference of the rotor blank.

The rotor blanks are then annealed and 24 holes drilled in each blank. The drilled blanks are placed on a rotating positioner and the cutting machine and torch team up to handle the precision oxygen-slotting operation. The cutting torch slices 36 in. of circumferential arc slots and 12 in. of radial slots — a total of 48 in. of exact $\frac{1}{16}$-in. slotting per rotor (Fig. 2). Time for slotting: only 11 min.

Following the slotting operation, the rotors are again annealed and then rough ground, broached, countersunk, heat treated, finish ground and deburred (Fig. 3).

Based on a story by the Linde Co., New York, N. Y.

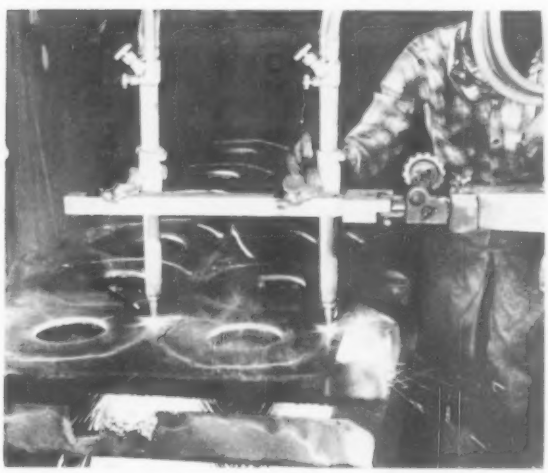

Fig. 1 Two brake rotor profiles are simultaneously flame cut by torches mounted on a cutting machine

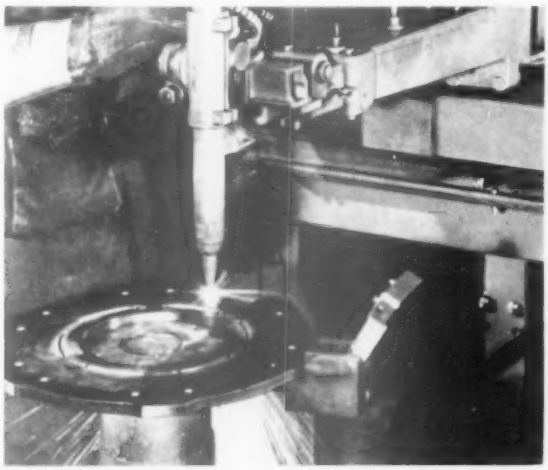

Fig. 2 Here slots $\frac{1}{16}$ in. wide are precision-cut in $\frac{7}{16}$-in. thick steel plate with the cutting torch

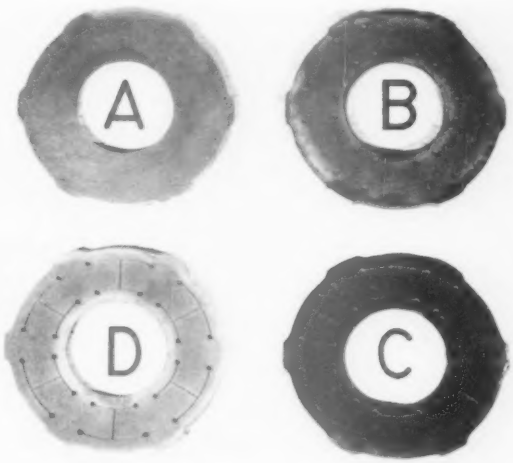

Fig. 3 Brake rotors in four stages of production: (A) after shape cutting, (B) after drilling, (C) after slotting, (D) after finishing

Society News

Topics of technical papers sought for AWS 40th Annual Meeting range from

Practical Applications to Research Investigations

A well balanced group of welding papers, ranging from practical applications to research investigations, is being sought by the Technical Papers Committee for presentation at the 40th Annual Meeting and Convention of AWS in Chicago during the week of April 6, 1959.

As announced by National Secretary Fred L. Plummer in the June issue of THE WELDING JOURNAL, prospective authors are invited to submit abstracts of previously unpresented and unpublished papers to AWS Headquarters prior to Aug. 15, 1958. All abstracts will be carefully reviewed and evaluated by the Technical Papers Committee, and authors will be notified regarding acceptance sometime in October. In addition to being presented at the Chicago Meeting, acceptable papers will be considered for publication in THE WELDING JOURNAL.

Certain requirements must be fulfilled in order to assure that a paper receives proper consideration by the Committee. Since the information given in the application form and abstract is the only measure of a proposed paper's acceptance for the program, it is extremely important that all questions be answered in full. Also, length of abstracts should be no less than 500 words and, preferably, not more than 1000 words. In addition, all major points of the proposed paper must be clearly covered. Whenever possible, abstracts should be accompanied by complete manuscripts.

A number of general topics has been suggested by the Technical Papers Committee as preferred subjects for the 40th Annual Meeting:

- Practical applications or "how-to-do" topics
- Machinery design and fabrication
- Structures
- Fabrication and maintenance of equipment used for radioactive applications
- Pressure vessels and storage tanks
- Equipment and pipe lines used in the petroleum industry
- Automation as applied to resistance welding, inert-arc welding and other welding processes
- Welding of castings and composite structures
- Welding of dissimilar metals
- Welding of aluminum, magnesium, zirconium, titanium, molybdenum and like metals
- Surfacing
- Brazing
- Soft soldering
- Welding of plastics
- Any other topics dealing with the educational and informative categories of welding production, engineering, design, research and metallurgy, provided that they fall within the scope of AWS activities

Author application forms were mailed to every member of AWS during the early part of May. Nonmembers or members seeking additional copies may obtain them by writing to AWS Headquarters.

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Resolution

Comfort Avery Adams

Comfort Avery Adams, first president and founder of the AMERICAN WELDING SOCIETY, quietly passed away on the evening of Feb. 21, 1958. He wasn't really sick. His loved ones were at his side to administer his needs, but his kindly heart was tired. Dr. Adams was 89 years old and had lived a full life. He had made many important contributions to engineering development and had received many, many honors.

During World War I, Dr. Adams was appointed by President Woodrow Wilson as Chairman of the Welding Committee of the Emergency Fleet Corp., which was given the task of speeding up Shipbuilding production with the aid of welding. The work of this Committee was perpetuated in the organization of the AMERICAN WELDING SOCIETY in April 1919. Comfort A. Adams was the founder of the SOCIETY and its first president. At about the same time he helped organize the American Standards Association, the American Bureau of Welding and eventually, the successor to the Bureau, the Welding Research Council. It would scarcely be possible to compile a detailed account of his many accomplishments.

Dr. Adams was one of the country's leading engineering educators, having taught at Harvard from 1891 until 1936, a period of 45 years. At the time of his retirement, he was Dean of Engineering at Harvard. Under his skillful guidance, literally hundreds and, perhaps, thousands of young engineers were taught to understand and appreciate the fundamentals of engineering. They were taught that the habit of thinking for oneself is essential, rather than the blind acceptance of prevailing traditions, or theories, which sometimes are based on unsound premises. He taught those who came in contact with him to search for the facts and the underlying reasons for these facts.

These young engineers and many others—contemporary workers, members of committees on which he served—came in contact with another side of Comfort Avery Adams. They were taught to appreciate human relationships, the necessity for human understanding, the need to appreciate the other fellow's viewpoint, tolerance for those who disagreed, and sympathy for the "underdog."

Among the many honors received, Dr. Adams particularly appreciated his election as a member of the National Academy of Sciences, and the awards of the Lamme, the Edison and the Samuel Wylie Miller Medals. He received an Honorary Degree of Doctor of Engineering from both Harvard University and the Case Institute of Technology.

Three branches of engineering were enriched by the work and efforts of Dr. Adams. These were . . . electrical engineering, pressure vessel codes and welding engineering. His ability and success in convincing conservative engineers as to the reliability of welding expedited the adoption of a number of codes. The Adams Lecture was founded in his name. He was the first Adams Lecturer.

In connection with the homage paid to Dr. Adams by the SOCIETY in 1957, the meeting was named the Adams National Meeting of the AMERICAN WELDING SOCIETY. President Dwight D. Eisenhower sent greetings and mentioned the "outstanding record of public service which won the abiding esteem and affection of his Fellows in the engineering profession." The President of the United States rightly stated that "his career is an inspiration and a challenge."

Now, in memory of this great humanitarian, teacher and engineer, be it resolved:

> That the AMERICAN WELDING SOCIETY place upon its records its appreciation and homage to its Founder and first President, Dr. Comfort Avery Adams, and that copy of this Resolution be sent to his family.

THINGS YOU SHOULD KNOW

(That Happened in May)

● May 5th marked the beginning of a strenuous 14-day trip during which your Secretary participated in an unusually large number of varied activities. Starting at the Americana Hotel in Miami Beach, he joined President-elect Hoglund at the annual meeting of the National Welding Supply Association and enjoyed the reception for NWSA President Ray Tarbell, heard four excellent, inspirational talks and other program features, observed the operation of the "contact booths" where representatives of manufacturers and supply dealers met to discuss mutual problems, and attended the cocktail party, dinner and water show held in the vicinity of the large swimming pool which forms part of the beautiful hotel gardens. One most pleasant evening was spent with President Tarbell and his business associate Ed Scott and their charming wives—all loyal friends with pleasant memories of contacts in Cleveland many years ago. Your Secretary also inspected the new exposition hall and auditorium now nearing completion in Miami Beach and facilities at the Americana, Fontainebleau, Carillon, Deauville and other hotels. Executive Secretary Fernley and his associates are to be congratulated for their effective handling of this successful meeting.

● An early flight on May 8th carried your Secretary to Cleveland where he was joined at the Hotel Cleveland by Chairman I. A. Oehler of the Constitution and By-laws Committee for a conference devoted to detailed suggestions as to how the present lengthy and detailed by-laws can be divided into a compact and simple set of basic by-laws covering those matters of direct concern to all members of the SOCIETY and a set of supplemental rules of operation covering routine activities for which the Board of Directors is properly and fully responsible. These suggestions will be presented to the Board of Directors for preliminary consideration at its meeting June 5, 1958.

The following morning your Secretary was privileged to inspect the new and enlarged plant of Board Chairman James F. Lincoln. AWS plans and policies were discussed with Mr. Lincoln and several of his associates, including President Irrgang, Vice-President Charlie Davis, Exec. Vice-President Roscoe and others, both before and at lunch in the plant dining room.

● The afternoon and evening were devoted to the Annual Symposium of the Cleveland Section. This included educational exhibits, three excellent technical papers at an afternoon session and a dinner meeting attended by more than 500 members and guests who heard a fine, thought-provoking address by Dr. G. H. True of Notre Dame University. Tom Dempsey was Symposium Chairman with Section Chairman Bill Mayor presiding and turning over his gavel to Chairman-elect Harry McBride. Seated at the speakers table were national officers including President-elect G. O. Hoglund, Director-at-large Ross Yarrow, District Director Harold Schultz, Ass't. Sec'y. Frank Mooney, your Secretary and section officers, as well as Harold P. Blum, to whom the Symposium was dedicated. Your Secretary was especially pleased to greet Frank Maine who in 1940 joined your Secretary (then chairman of the Cleveland Section) in organizing the first of these events which have been held each year since that time with great success.

● Another early flight carried your Secretary to Washington airport where

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he was met and driven to Gaithersburg, Md., for a conference with Mr. and Mrs. M. E. McPherson concerning the welding section of a new building code for the District of Columbia.

● Later Mrs. Plummer, who had been visiting in the Washington area, Mr. and Mrs. Alan Tarr, Dr. and Mrs. Loewer and the McPherson's son and daughter-in-law, all met at the McPherson's home before driving to Baltimore for the annual dinner and dance of the AWS Section at the Southern Hotel. During this delightful evening, planned by V. Miller and his committee, Chairman Charles Basel announced the new officers including Chairman-elect James Burnley and his top assistant R. E. Metins. Your Secretary presented a District Meritorious Award to George E. Linnert who was not able to attend the meeting in St. Louis. More than 200 members and their lovely ladies enjoyed this gay occasion which included a featured "Hawaiian" dancer in interpretations of the soft, melodious flowing songs of the islands.

● Monday morning found your Secretary and Ass't. Sec'y. Frank Mooney back in Cleveland to attend a conference of secretaries of engineering societies and to check facilities of the Statler-Hilton and Cleveland Hotels in connection with the 1962 Annual Convention and Exposition which will be held in Cleveland, April 9 to 13. Mr. Mooney attended the full three-day conference which was devoted to discussion of society problems.

● Director John Blankenbuehler met your Secretary at the Dayton Airport Tuesday morning a few minutes after eight, following another early start. The day was filled with inspections of the various plants and diversified manufacturing operations of Hobart Brothers in Troy, a two-hour paper-work session, luncheon at the Country Club with the Rotarians, including a dramatic demonstration of memory by association by a Dale Carnegie staff member, and conferences with Ed Hobart and several of his associates. A short drive to Dayton was followed by the dinner meeting of the Dayton Section with a coffee talk on SOCIETY activities by your Secretary and a quiz session with everyone answering 40 questions including one section each devoted to arc, gas and resistance welding, all questions being based on a specific WELDING JOURNAL or WELDING HANDBOOK reference. A panel of experts included C. Adams, R. Haus, A. Kolb, F. Schulmeister and W. F. Wellemeyer.

● Five prizes were awarded to the two with highest over-all scores and to the top score in each section. Neither Director Blankenbuehler nor your Secretary was a winner. Chairman Frank Gue presided. It was a pleasure to greet Vice-Chairman Richard Stratton, Secretary T. C. Falter, R. G. Weiler (seen the week before in Miami Beach) and many other members. The Section is planning an educational course on resistance welding for this fall. Returning to Troy, your Secretary enjoyed the hospitality of Director Blankenbuehler and his wife until the following morning and departure for South Bend.

● Vice-Chairman V. D. Bloxson of the Michiana Section had planned a unique promotional type meeting and arranged for your Secretary to participate on May 14th. Illness prevented Mr. Bloxson from being present to enjoy this unusual and successful meeting. His associate Ray Ostrom effectively presented the local Section material they had prepared and also gave an excellent illustrated "space visit" lecture following the special talk your Secretary had prepared covering various Section activities and outlining National Headquarters' programs. Chairman Walter Wille presided at the dinner meeting and also at a luncheon meeting of the Section Executive Committee. Secretary W. G. Fassnacht (who reports a fabulous collection of different ways his name has been written) met your Secretary at the South Bend airport and conducted him on an interesting tour through the extensive Bendix plants where welding is used in many forms in producing automobile and airplane parts.

● Representatives of hotels and the convention bureau were at the Dallas airport the following noon to welcome your Secretary and extol the virtues of this rapidly growing industrial area. The afternoon was spent visiting exhibits and talking with manufacturers' representatives at the Southwest Metals Exposition sponsored by ASM. A

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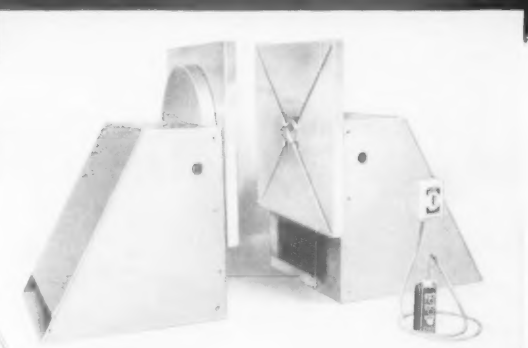

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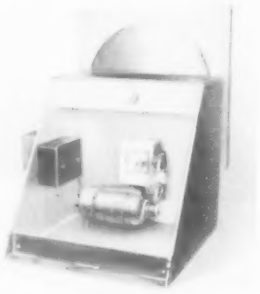

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pleasant evening followed at the Western Bar-B-Q and Dance as a guest of Bill Eisenman and Chester Wells. The next day started with a breakfast meeting of District 9 Section Officers organized by District Director Percy Pennybacker and Dallas Section Chairman C. L. Moss. The meeting was attended by several representatives of the Dallas, San Antonio and Houston Sections (including the Divisions of the Houston Section) and smaller delegations from most of the other Sections in District 9. The interesting discussions and reports continued throughout the morning. Chairman Moss and your Secretary then joined convention bureau, hotel and exposition hall representatives for lunch. The rest of the day was devoted to inspection of auditorium, exposition halls and facilities of the three leading hotels. Your Exposition Committee is considering the possibility of scheduling the 1963 Convention and Exposition for this area.

● Saturday, May 17th, the following day, began early with a flight to Chicago and on to the Detroit airport where Mrs. Plummer was waiting after a flight from Cleveland. A bus and taxi ride enabled your Secretary to reach Rackham Engineering Building in time for a conference with President-elect Hoglund and ten representatives of the Detroit Section concerning cooperation with the American Vocational Association in preparing a comprehensive welding instruction manual similar to the widely used Standards for Automotive Service Instruction in schools. Those in attendance included Chairman J. G. Kirkwood, Vice-Chairman Larry Kendall, Ray Stitt, W. M. Bateson, L. Wagner, D. Harvey, M. Thomas, K. Sheren, A. Althouse and C. Turnquist.

● In the evening President-elect Hoglund, Mrs. Plummer and your Secretary joined AWS members, guests and their ladies at the annual Ladies Night party of the Detroit Section—probably the largest party of its kind held each year by any AWS Section. An excellent dinner, announcement of new officers, brief remarks by President-elect Hoglund and your Secretary, a glamorous style show, a startlingly extensive list of valuable door prizes, and dancing continuing into the morning hours with coffee and cookies and a special favor for each lady, combined to make this a long-to-be-remembered occasion.

● Mechanical troubles and bad weather delayed the arrival back to Stamford until late Sunday evening.

● Tuesday, May 20th, President-elect Hoglund, First Vice-President-elect MacGuffie and your Secretary met with the New Jersey Section at Newark to hear Past-President Joe Humberstone present an unusual and stimulating talk, with a background of selected welding application pictures, all directed toward management, pointing out potential economies and advantages of welded construction. A large and enthusiastic crowd expressed their appreciation of this excellent address given with conviction and obvious enjoyment by Mr. Humberstone. Chairman E. DiLiberti presided and turned the meeting over to Program Chairman S. L. Sullivan following brief remarks by President-elect Hoglund.

● Preparation of a budget covering anticipated income and expense for the 1958-59 fiscal year requires much time of Treasurer H. E. Rockefeller, Asst. Treas. Frank Mooney, the SOCIETY auditors, your Secretary and other staff members. Conferences were held May 23rd, 26th and 29th in preparation for a joint meeting of the Finance and Executive Committees on June 4th and the Board of Directors meeting to be held June 5th.

● The sudden death on May 23rd of Herbert F. Reinhard saddened his many friends in the AWS, the IAA and throughout the welding industry. Mr. Reinhard had been Chairman of the AWS Public Relations Committee and also active on many technical committees.

● Invitations have been issued to all members to submit papers for the Annual Convention to be held in Chicago next April. The new Speakers' Directory has been mailed to all Sections. Two new booklets on "Opportunities in the Welding Industry," directed at different age groups, are taking shape and will soon be issued. The second section of the new WELDING HANDBOOK will be issued this fall. Committees for the third section are already at work. This section will include material on adhesive bonding and the welding of plastics. This is indicative of the progressive thinking of the SOCIETY and the desire to keep industry informed of the latest developments of metal-joining methods irrespective of whether the material used is metallic or nonmetallic.

● Word has just been received at AWS Headquarters that Technical Secretary Ed Fenton and his charming wife Elaine are the proud parents of a daughter, Ellen Carol, born May 26, 1958.

● Next month this column will include excerpts from the Annual Report of your Secretary.

Fred L. Plummer

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EDUCATIONAL ACTIVITIES

Section Leaflets

Early this year a leaflet was prepared for distribution at section meetings. This leaflet had two purposes in view: informational and educational. It was hoped, by this means, to keep the membership informed of important events and projects much faster than could be done through the medium of monthly publications. Obviously, the contents would be educational in nature since the project was conceived by the Educational Activities Committee.

The leaflet sent to AWS sections was in the nature of a trial guinea pig. We wanted to discover how the sections reacted to the idea and to determine if our own facilities were adequate for the work involved.

We are happy to say that some very favorable comments were received: ". . . received quite a bit of comment and we believe it would be worth while to have leaflets to distribute during the regular meetings. . ." and "I distributed these leaflets to all the members of the Sangamon Valley Section and they were received with much enthusiasm." Another member wrote, "We believe these leaflets will be very beneficial to the members as well as acting as a means of encouragement to prospective members." A fourth said, "I hope you will keep sending us up-to-date information each month in the form of leaflets that we can distribute at our monthly meetings."

We could have hoped for a greater response since the only guide we have is the reaction we get from the sections. These comments are sufficient, however, to make us feel we are on the right track.

Accordingly, we will continue the educational leaflets when the sections resume in the fall.

Speakers Directory

The Speakers Directory has been mailed to all sections and should have arrived everywhere before the end of May.

In all such publications it is inevitable that certain names are omitted. Pressure of business and illness cause unexpected delays and, since a deadline must be met, only the names received before press time can be included. We are hoping, however, to publish a supplement to the directory in the fall. Any company wishing to have speakers listed should send for a form.

Film Directory

The Film Directory, prepared by the Visual Aids Committee, is in good shape. It contains many new listings and should be a useful companion to the Speakers Directory. Certain additional companies have been requested to submit material, and when this information is obtained, the Directory will go to press.

We hope to have it printed and available to sections before the end of the summer.

Incidentally, Professor Wiley's Committee on Visual Aids came up with an excellent suggestion which may be invaluable to sections and schools. It was suggested that slides be prepared on a particular aspect of a subject and a talk developed to go with the slides. In practice, this would mean that talks would be available on a variety of subjects, with slides to illustrate them.

Booklets and Information

Every week at headquarters we receive many requests for information on welding. Some are from youngsters still in grade school and others from men employed in industry who wish to upgrade by means of education or training. We have the information available for many of these inquiries. When requests are for booklets, however, or for information of a local nature, we send a copy of the letter and our reply to the educational representative of the section nearest to the inquirer.

We have been greatly impressed by the comprehensive nature of the replies written by educational representatives. The appeals for information have been taken very seriously despite the youth of many of the writers.

The following letter is not an isolated example. It shows an earnest desire to help anyone, however young, get on the right track, despite the time and trouble involved:

Mr. ———
Miami 68, Florida
Dear Mr. ———

Your letter to the AMERICAN WELDING SOCIETY National Headquarters in New York has been referred to the local South Florida Chapter for answer.

We are happy to hear of your interest in securing knowledge on a career in welding. Welding of course covers a very broad scope, ranging from welding engineers engaged in designing structures and equipment and research into the welding processes, to the actual individual who performs the welding process of joining the various materials together. The actual welding process itself is performed with a large variety of materials and methods of joining, from automatic welding machines, to welding manually by hand.

To provide you with the information requested in your inquiry, we suggest that you do the following three (3) things:

1. Schedule a visit to our laboratory some afternoon after school, and see some welding tests performed and perhaps watch some structural welding. Call our laboratory in advance to schedule this visit.

2. If you will call me at NEwton 5-5317, I will be happy to direct you to some of the local welding supply firms who are members of our AMERICAN WELDING SOCIETY, and could provide you with welding pamphlets which might be usable in preparing your booklet.

3. Telephone Mr. Herbert Hoodwin, Structural Engineer, at Franklin 3-9845, and arrange with him to visit one of our local AMERICAN WELDING SOCIETY meetings here in Miami.

We feel that if you will follow the above listed three (3) suggestions, that you will have an opportunity to gain considerable basic knowledge of welding.

Very truly yours,
South Florida Chapter

This is just a little more proof that education is everybody's business.

1958 SPRING MEETING ABSTRACTS AVAILABLE

Complete sets of abstracts of the papers presented at the 1958 AWS Annual Spring Meeting in St. Louis, Mo., are now available at $2.00 per copy. Address your order to American Welding Society, 33 West 39th Street, New York 18, N.Y.

Section News and Events

as reported to Catherine O'Leary

Arizona

INERT-GAS WELDING

Phoenix, Ariz.—The last regular meeting of the season for the *Arizona* Section was held at the Sahara Hotel Sky Room on Wednesday, May 21st.

The guest speaker, George Allen of Kaiser Aluminum and Chemical Corp., presented a very interesting speech on the use of argon, chlorene mixture for welding aluminum by the inert-gas metallic-arc process.

California

RADIOISOTOPES

Huntington Park, Calif.—Members and guests of the *Aircraft & Rocketry Panel* of the *Los Angeles* Section had the pleasure of having an exceptionally fine paper presented at their May 1st meeting. The speaker was J. F. Young, physicist—group leader, at the Douglas Aircraft Co.'s Santa Monica Plant. Mr. Young discussed "The Application of Radioisotopes of Welding Research and Testing." In addition to a literature survey on the subject, the talk featured welding chemistry work done in his laboratory on welding problems.

FIELD TRIP

San Jose, Calif.—On Saturday forenoon, May 17th, 60 members and guests of the *Santa Clara Valley* Section visited the Manufacturing and Development facilities of the Atomic Power Equipment Department, General Electric Co., located in San Jose, Calif.

Members and guests were given a brief description and history of the Department which was organized in 1955 to meet the demand for development and production of civilian and industrial nuclear power. The General Electric Co. headquarters for this new and rapidly expanding industry were established in San Jose in 1956.

The visitors were conducted on a 90-min tour of the facilities where fabrication and testing of nuclear reactor components, instrumentation and fuel elements were observed. The manufacture of uranium-oxide fuel pellets and the welding of Zircaloy fuel rods proved to be points of great interest in addition to the complex equipment employed for testing reactor components.

YOUNG DISCUSSES APPLICATION OF RADIOISOTOPES

Leo West, chairman of Aircraft and Rocketry Panel, Los Angeles Section, opens May 1st meeting. Charles Smith, guest speaker J. F. Young and Howard Eubanks (*left to right*) are others shown

Speaker Young explaining to those present the application of radioisotopes to weld research and testing

Los Angeles Section officers Dick Hayes, Dave O'Connor, John Ross and Francis McGinley discussing future AWS events

Colorado

FABRICATING TECHNIQUES

Denver, Colo.—The regular monthly meeting of the *Colorado* Section was held on May 13th after a dinner at the Copper Kitchen Restaurant in Denver.

As has been the practice during the current year, a "Social Half Hour" was enjoyed before the dinner.

Wallace J. Erichsen, manager, Metallurgical Laboratory, Westinghouse Corp., Sunnyvale, Calif. Division, was the speaker for the evening. His talk covered welding and fabricating techniques used in the manufacture of turbines, heat exchangers, *gearing* wind tunnel parts, etc. He described the application of various automatic and semiautomatic welding processes used, along with metallurgical problems involved.

The speaker displayed samples of welds, showing the extreme accuracy of some of the joints employed.

This was an excellent presentation and much appreciated by the members.

Connecticut

PLANT TOUR

Bridgeport, Conn.—The April meeting of the *Hartford* Section was held on May 1st and consisted of a plant tour in conjunction with the *Bridgeport* Section through some of the facilities of the Lycoming Division of the Avco Manufacturing Corp.

After the tour, members of both sections met at the Fairway Restaurant in Bridgeport for dinner.

ANNUAL DINNER-DANCE

New London, Conn.—Lighthouse Inn in New London was the scene of the annual dinner-dance and installation of officers of the *Hartford* Section on May 23rd. Following a social hour 64 members and their guests sat down to a delicious lobster or roast beef dinner.

Outgoing Chairman Clint Swift, in a short talk, welcomed the members and their ladies and then proceeded to introduce George Kirkley, elected chairman for the coming season. In addition to Chairman Kirkley, the following new officers were introduced: vice chairman and program chairman, Willis A. Duneklee; secretary, Robert W. Anderson; treasurer, Vic Zdon; membership chairman, James Wiswall; hospitality chairman, Harvey Watrous; and technical representatives, Harry McGlew and John T. Ballass.

The remainder of the affair was turned over to Carl Olsen and his band for an evening of dancing and fun.

Florida

INSTALLATION OF NEW OFFICERS

Miami, Fla.—A buffet supper and installation of new officers for the *South Florida* Section was held as a final meeting of the year on May 21st at the usual meeting place, the Miami Firemen's Benevolent Association Hall. The following officers were installed: chairman, Joseph J. Gray, chief engineers-general manager, Biscayne Tank Mfg. Co., Inc.; 1st vice chairman, Theodore C. Buhler, president Miami Ship Building Corp.; 2nd vice chairman, Paul H. Marshal, supt. Steel Inspection Division, Pittsburgh Testing Laboratory, Miami Branch; treasurer, Harold Hose, supt. Sheffield Steel Products Inc.; and secretary, Zara Hamburger, Building Division, City of Miami.

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OUTER SPACE

Miami, Fla.—The last of the regular meetings of the season of the *South Florida* Section was held on May 19th at the Miami Firemen's Hall. Thirty-three members and guests attended the buffet supper meeting.

Guest speaker of the evening was Norbert Gariety, who has as his topic, "Visitors of Outer Space."

Mr. Gariety asked the question: "Is there another form of life in the planet system?" and then proceeded with his lecture, illustrated with slides, bringing together considerable information gathered from the four corners of the earth. His talk was most thought-provoking and enjoyed by all.

Illinois

WORKMANSHIP STANDARDS

Peoria, Ill.—The *Peoria* Section's regular meeting was held on April 23rd at the Meeca Supper Club. The speaker was Howard B. Cary AWS, of the Marion Power Shovel Co. He spoke on "Maintaining Workmanship Standards for Quality Welding," particularly as applied at the Marion Power Shovel Co. Mr. Cary went into detail on procedures, and how quality was maintained within their specifications.

Indiana

FLUX-CORED-ELECTRODE WELDING

South Bend, Ind.—At the April dinner meeting of the *Michiana* Section held on April 24th at Russ' Restaurant in South Bend, J. A. Howery AWS, assistant manager, Technical Service Department, National Cylinder Gas Division, Chicago, discussed the advantages of the new welding process which uses a flux-cored filler metal and CO_2 gas for a shield. Using the combination of flux and gaseous shield seems to bring out the better functions of both of these methods, fast welding speeds, low splatter loss, sound welds, etc., being properties of this method of joining. Some high-speed movies of this and other welding arcs showed the reasons for some of the above properties. Another film showing applications of the double-shielded arc-welding process was also shown.

AWS ACTIVITIES

South Bend, Ind.—The *Michiana* Section finished its season with a presentation on the AMERICAN WELDING SOCIETY ably given by National Secretary Fred L. Plummer. It was on May 14th that 55 members and guests gathered to hear Mr. Plummer describe the organization of the SOCIETY and the work that headquarters is doing.

Following Mr. Plummer's talk, a fanciful flight into space was presented by Ray Ostrom AWS, of the Durakool Corp. Pictures of and by the Polomar Astronomical Group showed what one might encounter were he able to leave the confines of our earth and to wander among the stars.

Announcement was made of the newly elected officers as follows: Ray Bloxson, chairman; John Weis, vice chairman; Gerard Fassnacht, secretary; Leo Cuthbert, treasurer; Jake Miller, executive committee; Floyd Doolittle, executive committee; and Everette Lyerla, executive committee.

Kansas

PLANT TOUR

Wichita, Kan.—On May 12th, the last meeting until Fall, the *Wichita* Section met at Boeing's Wichita Division, Plant No. 2 for dinner in the company cafeteria at 6:30 and a plant tour at 7:30. The tour covered the machine-shop area where they watched tape-controlled contouring machines, the resistance- and fusion-welding production shop, the metal-bond area, the chemical-processing area, the tape-controlled skin mill area, subassembly and final assembly. AWS members Glenn Woodmancy, Paul Carter, Earl Krasser and Duane Waugh from Boeing guided the tour and answered questions.

Kentucky

FLUX-CORED-ELECTRODE WELDING

Louisville, Ky.—The *Louisville* Section ended its meeting year with a full and enjoyable evening on May 27th, which included dinner, the showing of Socony Vacuum's film "Indianapolis Speedway Race of 1957" in color and with sound, election of officers, and the presentation of "New CO_2 Welding Process" by James A. Howery AWS, technical service supervisor, National Cylinder Gas Division of Chemetron Corp.

According to Mr. Howery, the new welding process utilizing a flux-cored electrode and a carbon-dioxide shield,

MARYLAND SECTION CELEBRATES WITH DINNER AND DANCE

Gala gathering marked the dinner and dance given by the Maryland Section on May 10th. Seated at head table with Section officers are National Secretary and Mrs. Fred L. Plummer

Secretary Plummer presenting Meritorious Certificate Award to George B. Linnert

was developed with the objectives of providing both an automanual and automatic process that would allow the operator to see the arc, deposit sound weld metal at a high rate and obtain economical weldments.

Mr. Howery explained that CO_2 gas excludes air from the arc and molten metal and introduces a measured amount of oxygen into the weld pool. The oxygen combines with some of the flux compound to clean and purify the weld metal. The flux from the cored wire helps to exclude the atmosphere and introduces an ionizer to stabilize the arc, a deoxidizer to reduce mill scale, and slag formers.

New Section officers for the fiscal year are: chairman, David C. Brown; vice chairman, W. H. Cochran; secretary, Walter Wood; and treasurer, Eugene Schade.

Maryland

Baltimore, Md.—On the evening of May 10th, the *Maryland* Section held their third annual dinner and dance, which was attended by 215 members and their ladies. The affair was held in the Colonial Room of the Southern Hotel in Baltimore.

All those present were pleasantly preheated during the cocktail hour and enjoyed a roast turkey dinner.

Following the dinner, the newly elected officers took over their new assignments and National Secretary Fred Plummer presented the Meritorious Service Award to George Linnert.

Group singing of old and new songs was led by the wandering accordianist, and numerous door prizes were given to those holding the lucky numbers. Finally, dancing and congeniality reigned supreme when the "Diplomats" let loose with their musical renditions.

At the close of the evening, one and all agreed that the evening's festivities had been enjoyed by all and they are looking forward to next year's affair.

Michigan

QUIZ THE EXPERTS

Detroit, Mich.—The *Detroit* Section held its annual "Quiz the Experts" program on Friday, April 11th. The competing teams from Indiana, Toledo and Anthony Wayne Sections were very evenly matched with Detroit coming out on top with a score of 560 points and Indiana second with 515 points. This annual event is one of the highlights of the Detroit Section and the keen competition makes a very interesting program.

The coffee speaker, W. G. Cryderman, president of Kaybar, Inc., Birmingham, Mich., gave a very interesting talk on "Today's Magic Carpet," a topic dealing with modern aviation and modern navigation of small aircraft.

The section held two special technical meetings, one on April 23rd when Steve Yasko (M), of Westinghouse, spoke on "Gas-Shielded Metal-Arc Welding"; and the other meeting on April 24th when Edmund F. Holt (M), of P. R. Mallory and Co., spoke on "Resistance Welding Electrodes."

DETROIT SECTION HOLDS LADIES NIGHT PARTY

Mrs. Tom O'Brien, winner of grand door prize, shown with Chairman-elect Larry Kendall (*left*), and Chairman Gordon Kirkwood. Affair was held on May 17th at the Latin Quarter in Detroit

LADIES NIGHT

Detroit, Mich.—The *Detroit* Section held their Annual Ladies Night Party on May 17th and a wonderful time was had by the 813 members and guests who were on hand to greet National President-elect Gus Hoglund and National Secretary Fred Plummer. Mrs. Plummer presented the Grand Door Prize to the winner. One hundred and fifty door prizes were presented to the ladies. The dinner and style show which followed were thoroughly enjoyed by everyone. The new officers were introduced as follows: chairman, Larry Kendall; 1st vice chairman, Ray Wilcoxson; 2nd vice chairman, Art Brown; treasurer, J. R. Stitt; secretary, Ray Wolgast; asst. secretaries, Jim Cox, Al Lindsay and R. Zacharie; and executive board members, Les Wagner, Doug Harvey, John Childs, Stan Coltson, Len Broniak, Jim Morrisey, Harry Beronius, Bill Jones, Jack Lemon, Graham Dick, Gerry Wilson, Porter Struther, Geo. Motzenberger, Roger Vogel and Joe Sarlanskas.

MAGNETIC FORCE WELDING

Detroit, Mich.—To wind up the season, the *Detroit* Section held a very interesting and timely technical session on May 22nd, when about 175 members and guests heard a talk on welding vinyl-coated steel as given by A. W. Schueler [M], chief development engineer for Precision Welder and Flexopress Corp. This technique is quite new and opens a large field for resistance welding.

Missouri

ELECTION OF OFFICERS

Kansas City, Mo.—The *Kansas City* Section has announced the election of the following officers: chairman, Delmar Burrows; vice chairman, J. R. Warn; secretary, Larry Thompson and treasurer, C. J. Sisc.

New Jersey

WELDED-PRODUCT DESIGN

Newark, N. J.—On Tuesday evening, April 22nd, the *New Jersey* Section held its regular monthly dinner meeting at the Essex House Hotel. The dinner, attended by 45 members and guests, was immediately followed by a motion picture entitled, "Whatever We Do" shown through the courtesy of the Air Reduction Co., illustrating how the many gases are extracted from the atmosphere and put to use in industry.

Approximately 85 members and guests gathered to hear the featured speaker for the evening, John Mikulak [M], assistant to the vice president in charge of manufacturing at Worthington Corp., Harrison, N. J. With his background, Mr. Mikulak was well qualified to speak on his chosen subject, "Product Design for Welding." With the aid of projected slides he covered basic design using composite components of steel castings, rolled sections, pressings and extrusions, stressing simplicity and good fit-up for low-cost construction.

New Mexico

NONDESTRUCTIVE TESTING

Albuquerque, N. Mex.—The *Albuquerque* Section held its annual meeting on May 8th at La Hacienda Dining Room. The wives of the members were invited and many were present. The results of the election of officers were announced and the new officers were installed as follows: chairman, William H. O'Brien; 1st vice chairman, Gale S. Hanks; 2nd vice chairman, V. G. Nelson; secretary, Frank Gonzales; treasurer, George Elkins; and members at large, John Voller and Max Gonzales.

QUIZ-THE-EXPERTS NIGHT

Coffee speaker at the April 11th dinner meeting of Detroit Section was W. G. Cryderman

Bob Bennewitz was the moderator who presided over the technical program

Teams of experts from four sections competed for the evening's honors. Shown above are the representatives from the Indiana, Toledo, Anthony Wayne and Detroit Sections. Moderator Bennewitz is at extreme right

The Section's official gavel, an antique cutting torch made in Budapest, was presented to the new chairman.

Following the dinner an interesting illustrated talk on nondestructive testing was given by Donald Grimm of Los Alamos Scientific Laboratory. Mr. Grimm spoke on the use of dye penetrant inspection, magnetic particle inspection, radiography and high-energy isotope sources as they apply to the inspection of weldments.

The Albuquerque Section is looking foward to the new season with the anticipation of making it the best ever.

New York

MACHINE-TOOL WELDING

Kenmore, N. Y.—At the April 24th meeting of the *Niagara Frontier* Section, 60 members heard John H. Berryman [illegible], of the Machine Welding Department, Air Reduction Sales Co., speak on "Machine Tools for Welding."

Mr. Berryman told how several companies were custom-building these devices which fusion weld production quantities of one specific part with little attention from the operator other than loading of parts. The machine automatically positions and clamps the part and then follows a pre-determined welding sequence. As an example of the integration of functions, one machine for welding strip also shears and cleans it.

The speaker emphasized that these machine tools must be the result of a cooperative effort between the tool engineer and the welding engineer. He said that an advantage of buying a custom-builder is that the builder guarantees the machine to perform the job for which it was designed.

The speaker showed slides of equipment ranging from manipulators having wide applicability to units which were so specialized as to have little value once the intended usage was completed. Particularly impressive were the views (just released for publication) of the giant fixtures for welding 10-ft diam aluminum propellant tanks for the Titan missile.

PLANT TOUR

Wellsville, N. Y.—The regular meeting of the *Olean-Bradford* Section was held at the Fassett House in Wellsville on Tuesday evening, May 20th. There were 46 present for the dinner and they later made a tour of the plant of the Air Preheater Corp. in Wellsville.

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WELDING OF VINYL-COATED STEELS EXPLAINED BY SCHUELER

Two views of the large audience in attendance at the special technical meeting held by the Detroit Section on May 22nd

Coffee speaker Nick Kerbawy addressing the members and guests present

T. Embury Jones introduced the technical speaker of the evening, A. W. Schueler

Mr. Schueler's topic dealt with the magnetic force welding of vinyl-coated steel

NEW DEVELOPMENTS IN WELDING IS THEME OF CLEVELAND SYMPOSIUM

(*Left to right*) President Gus Hoglund, A. F. Davis and Irving Schreck listen attentively to Symposium Chairman Tom Dempsey during social hour

Harold Blum (*left*) and Secretary Fred Plummer apparently like James F. Lincoln's jokes. Symposium was dedicated to Mr. Blum

Cleveland Section Chairman Bill Mayor adjusts microphone for Symposium speakers (*left to right*) James Howery, W. H. Helmbrecht and Albert Muller

Chairman Mayor presents plaque honoring, posthumously, the contributions of Lew Gilbert. Chuck Berka accepts plaque on behalf of Mrs. Gilbert

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North Carolina

INERT-GAS WELDING

Raleigh, N. C.—On April 28th, the regular meeting of the *Carolina* Section was held in the Colonial Room of the S & W Cafeteria.

The guest speaker for the evening was W. F. Ruehl [M], manager of the Gas Products Division, Southern Oxygen Co., Washington, D. C. Mr. Ruehl talked on the inert-gas metal-arc and inert-gas consumable-electrode arc welding processes. Included in the talk was an excellent description of the manufacture of argon gas.

A color sound film was shown through the courtesy of Alcoa on "Welding Advances with Aluminum" with animated sequence showing how the metal is joined with illustrations of tanks and pressure vessels.

Ohio

WELDING SYMPOSIUM

Cleveland, Ohio.—The *Cleveland* Section held its annual welding symposium on May 9th. All of the various activities of the day proved to be highly successful. A group of educational exhibits attracted many visitors and afforded an opportunity to exchange ideas among men from many areas of the metalworking field. The technical papers session in the afternoon drew a large audience which was rewarded with a great deal of useful information. The theme of the symposium was "New Developments in Welding." The dinner attended by over 500 members and friends offered recognition to many who have been working for the Cleveland Section. The large group also heard an excellent talk on the subject of "creativity" by Dr. Herbert True of Notre Dame University.

Speakers on the afternoon technical program were James Howery of National Cylinder Gas who discussed CO_2 welding; Dr. Albert Muller of Air Reduction Sales who spoke on welding HY-80 steel; and W. H. Helmbrecht of the Linde Co. who described several new welding processes. Bill Mayor, the Section chairman, presided at the technical session in place of Clayt Herrick, technical chairman, who had been unavoidably absent.

The dinner meeting was conducted by Tom Dempsey, first vice chairman of the Section, who was the general chairman for the Symposium. He presented a gift from the Section to Harold Blum, district representative for Metal and Thermit, to whom the Symposium was dedicated in recogni-

Correction:

On pages 502 and 503 of the May 1958 JOURNAL, the titles of the talks given by James A. Hoovery before the Dayton and Fox Valley Sections were given as "Automatic and Semiautomatic Welding Equipment Using the Carbon-Dioxide Magnetic-Flux Welding Process" and "Carbon-Dioxide Magnetic-Flux Welding."

These titles should have read, respectively, "Automatic and Semi-automatic Welding Equipment Using the CO_2-Shielded Flux-Cored-Electrode Process" and "CO_2-Shielded Flux-Cored-Electrode Welding."

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tion of his 28 years of faithful service to the Section in many different capacities. The Section also officially made a posthumous recognition of Lew Gilbert's many contributions to both the Society and to the Section.

New officers of the Section for 1958-59, installed at the meeting, were Harry E. McBride, chairman; Thomas L. Dempsey, first vice-chairman; Irving E. Schreck, second vice-chairman; and Raymond Metzger, Jr., secretary-treasurer.

QUIZ PROGRAM

Dayton, Ohio.—The guest of honor at the May 13th meeting of the *Dayton* Section was National Secretary Fred L. Plummer who gave a short but very interesting rundown of the activities and functions of national headquarters.

A panel of experts gave the brain cells of all present a good workout with their multiple choice welding quiz. As a result of the high scores prizes were carried off by the following: Bob Bowman, an aluminum folding table for high over-all score; Glyn Williams, a portable fan for second highest over-all score; Don Aughe, two aluminum folding chairs for high score in gas welding; Bernard Berchtold, a folding aluminum lounge for high score in arc welding; and Orville Martin, a folding aluminum lounge for high score in resistance welding.

Pennsylvania

LADIES NIGHT

Bethlehem, Pa.—The *Lehigh Valley* Section held its annual Ladies Night and installation of new officers on May 10th in the Ballroom of the Hotel Bethlehem.

Prof. Cyril D. Jensen was installed as the new chairman. The other newly elected officers were: L. R. Constantine, vice chairman; L. J. McGeady, secretary-treasurer; and M. Frank Couch and Thomas Fitzgibbons, directors.

ELECTION OF OFFICERS

Philadelphia, Pa.—The annual dinner-dance of the *Philadelphia* Section which had originally been scheduled for May has been rescheduled for June.

The officers elected for the ensuing year are as follows: chairman, Carl M. Schaub; vice chairman, Frank Iapalucci; secretary, Walter H. Wooding; treasurer, K. Wm. Ostrom; publicity chairman, Veryl V. Meixell.

MAINTENANCE WELDING

Johnstown, Pa.—A special Jamestown Area meeting was held by the

LEHIGH VALLEY SECTION MEMBERS HONOR THEIR LADIES

Pictured with their wives at the May 10th Ladies Night event sponsored by the Lehigh Valley Section are the new officers for 1958–59 fiscal year: (*left to right*) Secretary and Mrs. L. J. McGeady, Chairman and Mrs. C. D. Jensen, and Vice-Chairman and Mrs. L. R. Constantine

R. A. Bartholomew (*left*), retiring Section chairman, receiving past chairman's pin from Chairman Jensen

Pittsburgh Section on May 15th for the many interested members and guests in that area.

Featured speaker was Cares Keyser AWS, welding engineer, Steelton Plant, Bethlehem Steel Co. Mr. Keyser's illustrated talk was on "Maintenance Welding and Hard Surfacing."

Rhode Island

WHY WELDS FAIL

Providence, R. I.—Helmut Thielsch AWS, metallurgical engineer with Grinnell Co. Inc., was principal speaker at the March 19th meeting of the *Providence* Section held at Johnson's Hummocks, with nearly 100 members and guests attending.

Mr. Thielsch, who is also chairman of the Section, presented a plain down-to-earth discussion on the following five basic causes of failures in weldments:

1. Improper engineering design of structures or "difficult-to-weld" joint design.
2. Incorrect indentification, selection and specification of materials (base metals and welding filler metals).
3. Defects in the base metal or weld metal caused by faulty steel-making practices, careless steel forming, shaping or heat treating, improper electrodes, etc.
4. Defective welding (lack of penetration, root pass cracking, etc.).
5. Failure due to service conditions, such as overheating.

He also explained in detail that failures in weldments due to defective welding are, by far, the exception. Although the final customer or user is inclined to blame weldment failures on the welder or welding fabricator, only in an isolated few instances has this been substantiated. Welding fabricators, therefore, should not accept rejections or back charges for repairs without first analyzing the actual causes of failure or the reasons for the rejection. Most engineers do not yet appreciate that the filler metals (electrode and welding wires) used are produced to far more exacting standards and closer chemical composition controls than base metals. Welds now produced are, in general, stronger and sounder than the adjacent base metals. The welding profession should be proud of the quality produced by welding and, when needed, fight for it.

The talk accompanied by very descriptive slides was informative, as well as educational, and was followed by a lively discussion period.

Tennessee

CONSTRUCTION MATERIALS

Clinton, Tenn.—The *Northeast Tennessee* Section met on April 22nd for dinner and meeting at Thompson's Drive-In Restaurant in Clinton.

The speaker was J. M. Bates AWS, of the Union Carbide Nuclear Co., South Charleston Plant. His subject was "Materials of Construction Commonly Used in the Chemical Industry." Special emphasis was made of the important part which welding has played in the utilization of these materials for chemical-plant equipment.

Texas

LOW-HYDROGEN ELECTRODES

Houston, Tex.—D. C. Helton AWS, contact metallurgist, Harnischfeger

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LOW-HYDROGEN ELECTRODES EXPLAINED BY HELTON

Guest speaker D. C. Helton presents his talk on "Late Developments in Low-Hydrogen Electrodes" at April 23rd meeting of Houston Section

Evening was also marked by an extremely fine turnout of members and guests as shown above

DINNER-DANCE GIVEN BY HOUSTON SECTION

A number of the Houston Section officers shown with their ladies at the dinner-dance held on May 24th

"Chow-line" was a popular place all evening, as can be seen above by the many "customers" on hand

Outgoing Chairman and Mrs. Roy Pringle beam with delight while holding gifts presented to them by the Section

Corp., Milwaukee, Wis., presented an excellent talk on the "Development of Low-Hydrogen Electrodes," at the April 23rd meeting of the *Houston* Section held at the Ben Milam Hotel.

This type of electrode had its origin during World War II. An electrode was needed to weld hardenable steels, such as armour plate, for tanks, vehicles, etc., besides using the stainless series electrodes. The low-hydrogen electrode was developed to meet this need.

Many charts were shown which described the composition and characteristics of the E7016A (conventional), E7018 (30% iron powder), and E7028 (50% iron powder) types.

Very high-tensile strengths in welds can be developed by welding the SAE 4140 and 4340 steels followed by heat treating and tempering. This advantage is being exploited by the aircraft missile industries.

DINNER-DANCE

Houston, Tex. — The *Houston* Section ended the program year with an exceptionally fine social occasion on Saturday night, May 24th. There were 153 members and guests present at a dinner-dance held at the Houston Home Builders Association Auditorium.

Arrangements and ticket sales for the affair were headed by Tom Potter who secured the services of Bob Smith and his orchestra and the Lennox Catering Service. This combination made outstanding entertainment for the ladies and gentlemen present.

This is the second year for the dinner-dance which appears to have taken hold as an annual event.

The new officers and directors (with their wives) were introduced as follows: chairman, Hubert F. Crick; vice chairman, Malcom C. Avis; 2nd vice chairman, Don J. Middlehurst; secretary-treasurer, Luther L. Manchester; asst. secy.-treas., Howard H. Olson; directors of 1958–60, Robert C. Anderson, David C. Kegg, Edward T. Looney, Frank A. Lyle, John R. Pratt and Roy P. Pringle; and directors for 1958–59, Albert A. Averbeck, Leroy M. Barbin, Joe E. Compton, L. E. Derben, E. L. Hilderbrank and P. D. Morgan.

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#2/0	370.00	409.00
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New Members

Effective May 1, 1958

MEMBERSHIP CLASSIFICATION

A—Sustaining Member B—Member C—Associate Member
D—Student Member E—Honorary Member F—Life Member

Total National Membership

Sustaining Members	181
Members	6,098
Associate Members	5,933
Student Members	207
Honorary Members	8
Life Members	15
Total	12,442

Support Your Society—Be Active!

ANTHONY WAYNE

Goins, Robert J. (B)

BATON ROUGE

Mire, Louis J. (B)

BOSTON

Crane, Theodore H. (B)
Rufo, Buono B. (B)
Somoza, Carlos (D)

CANADA

Richmond, John (B)

CAROLINA

McKnight, E. M. (B)

CHICAGO

Gliniewicz, Joseph (C)
Matasovic, Wm. R. (C)
Unger, Kenneth R. (C)
Wollard, B. G. (B)

CINCINNATI

Mueller, Ronald H. (B)

CLEVELAND

Koeth, Chester John (C)
Schick, W. R. (C)

DALLAS

Clark, J. M. (B)

DETROIT

Bowditch, William (C)
Ekstrom, Kenneth A. (B)
Gove, Robert L. (B)
Zisk, Edward (B)

FOX VALLEY

Lemmers, Patrick M. (C)
Rasmusen, Reidar P. C. (B)

HOLSTON VALLEY

Bowling, Van D. (C)
Doty, Wilbur Lee (C)
Shipley, Ray L. (C)

HOUSTON

Hendricks, John R. (B)
La Fleur, S. O. (B)
McGinley, Robert J. (B)

LEHIGH VALLEY

Ferreira, Anthony (B)

LONG ISLAND

Bedell, John R. (B)

LOS ANGELES

Hays, Wendell M. (D)
Jensen, Clarence D. (B)
Mustard, B. L. (C)
Rhinehart, Michael J. (C)
Williamson, Robert L. (C)

MAHONING VALLEY

Gallo, Thomas S. (B)
Grim, Robert O. (C)
Lynn, John P. (B)

MICHIANA

Huffman, James (B)

MILWAUKEE

Chase, James William (C)

NEW JERSEY

Pogue, Walter H., Jr. (C)

NEW ORLEANS

Dutrechon, Raymond E. (B)

NEW YORK

Kandel, Richard C. (B)
Ritzert, George (B)
Stephenson, Elliott O. (B)
Throckmorton, John W. (B)

NIAGARA FRONTIER

Campbell, W. P. (B)
Youngs, Wallace J. (B)

NORTHERN NEW YORK

Barry, Edward L. (B)

NORTHWEST

Fashbaugh, Elmer F. (B)
Heron, J. H. (A)
Mikkola, Clifford J. (B)
Papenhausen, M. (C)

OKLAHOMA CITY

Carter, John E. (C)
Chaffant, G. B. (C)

PHILADELPHIA

Henry, Edward J. (B)
Mayne, William E. (B)
Phipps, Wesley W. (B)
Wall, R. Bruce (A)

PITTSBURGH

Mason, Henry F. (C)
Speranza, Bernard E. (B)

PORTLAND

Anicker, Donald (D)
Carlson, William R. (D)
Donk, Robert (D)
Duralia, George L. (D)
Field, Ralph (D)
Folk, Delbert P. (B)
Frantz, Lloyd (B)
French, Lawrence A. (B)
Green, Roy E. (B)
Lomax, Charles D. (B)
McCoy, Darrell W. (D)
Miller, Don B. (B)
Nydigger, James D. (D)
Overcash, Wayne J. (D)
Paterson, Ronald W. (D)
Phillips, G. L. (B)
Ropp, Roy Lee (D)
Rothrock, Berle D. (D)
Schiewe, Kenneth (D)
Tompkins, James H. (D)
Van Newkirk, Gene L. (D)
Wilch, Donald A. (D)

PROVIDENCE

Confreda, James W. (B)
Gendreau, Raymond A. (B)
Harvey, John L., Sr. (B)
Olson, Richard A. (B)

PUGET SOUND

Kribs, Louis Edward (B)
Mac Leod, Roderick K. (C)
Peterson, Kenneth F. (B)

RICHMOND

Phelps, D. H. (B)

SAGINAW VALLEY

Lockwood, Lloyd F. (C)
Palentyn, Gunther H. (C)

ST. LOUIS

Greenway, Frank (C)
Savn, August R. (B)
Vest, G. G. (B)

SALT LAKE CITY

Greer, Rex Y. (B)

SAN FRANCISCO

Kropp, Augie (B)
Lennington, Harold L. (B)
Stout, Daniel C. (B)
Such, Theodore E. (B)

SANTA CLARA VALLEY

Blau, Roy Charles (D)
Hunnicutt, Richard Pearce (B)

SOUTH FLORIDA

Roy, Robert H. (C)

SYRACUSE

Black, Clayton T. (C)

TOLEDO

Ball, John C. (C)
Richman, Raymond F. (B)

TULSA

McWilliams, William E. (B)

WESTERN MICHIGAN

Bracken, Darwin H. (C)
Kunsch, Robert (C)

YORK-CENTRAL PA.

Baker, Douglas H. (B)
Smith, Paul H. (B)
Snyder, Carl V. (C)

MEMBERS NOT IN SECTIONS

Brieda, Jean (B)
Hill, Howard B. (C)
Ladyjensky, Uri Samuel (C)
Miller, M. M. (C)
Naruse, Katsutake (B)
Price, J. O., Jr. (C)
Read, Gordon A. (B)
Swan, Robert L. (C)

Members Reclassified

During the Month of May

CHICAGO

Bernard, Richard A. (C to A)

CLEVELAND

Uher, Otto A. (C to B)

DETROIT

Fullenwider, Allan C. (C to B)

HOUSTON

Douglas, Warren R. (C to B)

LONG BEACH

Blake-Hedges, John C. (C to B)
Cary, Ronald G. (D to B)
Deroueher, William T. (C to B)
Spillman, W. J. (C to B)
Teeter, Malton A. (C to B)

NEW JERSEY

Axtell, A. C. (B to A)
Benson, Cornell (C to B)
Schmidt, Howard (C to B)

NEW YORK

Holland, S. Emil (C to A)

PITTSBURGH

Bibber, L. C. (A to E)
Nichols, H. J. (B to A)

ROCHESTER

Nash, William H. (C to B)

ST. LOUIS

Pandjiris, A. K. (B to A)

SHREVEPORT

O'Connell, Joseph E. (C to B)

SUSQUEHANNA VALLEY

Williams, William J. (C to B)

NATIONAL WELDED PRODUCTS MONTH

Remember September

AS THIS YEAR progresses, the American public will come to recognize the importance of welding . . . we hope.

Our campaign to promote September as National Welded Products month at last seems to be catching hold, and we are especially pleased with our readers who write in to ask "What can I do to help?"

All of us who deal with the welding processes—so ideally suited for joining metal—want welding to get the acclaim it deserves. This recognition, in turn, will help promote a stronger, more vital industry.

Welding, a basic essential to scores of products, is often accepted without questioning. It is there—unobtrusive and unnoticed. With your cooperation, we can make people look, and see, how great a part welding plays in their businesses, their homes and their lives.

How do we start?

For those in the welding industry, a favorite topic of conversation should be welding . . . every newspaper, magazine and piece of advertising should carry the "Remember September" slogan . . . wear tags, print signs . . . do all the things important to a good campaign. Discuss, explain, promote, sell welding. News travels fast by word-of-mouth.

If you work for a firm that turns out welded products, suggest to the executives, particularly the advertising manager, that from now through September your ads mention the fact that your product is welded. A sure way to point out National Welded Products month is to have a reproduction of the insignia shown here (greatly reduced, of course) inserted in all your advertising. WELDING ENGINEER will be happy to send you a one-color proof suitable for reproduction.

If your company manufactures equipment used in welding, or welding rods and supplies, you will want the public to know that the finest products are created through welding. Mention it in your ads!

September is only three months away. We will have to work hard and fast, but by the end of September, all America should have the word "welding" on its lips, and in its mind—the knowledge that welding turns out the best products, gives the best results.

The National Welded Products Month activity deserves support. We are, therefore, pleased to cooperate by reproducing, herewith, an announcement which appeared in the June 1958 issue of the Welding Engineer.

Welding Journal Editors

BECKER

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FOR CONSISTENTLY GOOD RESULTS

Designed to carry the high currents necessary for intense heat, BBB Keen-Arc Carbons produce a fine-grained weld of high tensile strength. They give a smooth, steady "flowing" flame which does not wander and which is concentrated at the desired focal point. Flame temperature is easily and accurately adjusted by merely changing the ampere input, and heavy copper coating permits gripping at extreme ends—eliminates frequent and periodic resetting.

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- **How Do They Get There?**
- **Are They Dangerous?**
- **How Can You Get Rid of Them?**

Prof. R. Weck of Cambridge University and Director of the British Welding Research Association, will be brought to America this October to deliver seven important lectures on residual stresses. Coupled with these outstanding lectures will be seven discussion periods by 14 American experts.

This Seminar will be held during the latter part of Metal Show Week

October 30, 31 and November 1, 1958

Place: Wade Park Manor, Cleveland

Registration Fee: Including lunches and dinners for the three days, $150.00. (Early registration with $25 deposit suggested.)

Mail your reservation now—or write for folder giving complete details of this important ASM Metallurgical Seminar to

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PRE-WAR WELDER*	POST-WAR A. O. SMITH*
Average Copper Coil Weight 180 lbs.	**Copper Coil Weight 186 lbs.**
Height 46 in.	**Height 47½ in.**
Temperature rise — 55°	**Temperature rise — 55°**

*500 amp heavy-duty a-c welder

NOTE: A. O. Smith also offers the *Challenger* line of a-c welders competitive in size and strength with today's "so-called" heavy-duty units.

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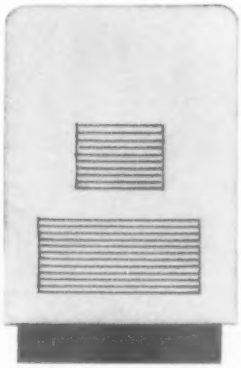

PRE-WAR WELDERS*

Average Copper Coil Weight 180 lbs.

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Average Temperature rise 55°

*Heavy-duty a-c (500 amps)

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Average Temperature rise 120°

*Heavy-duty a-c (500 amps)

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The amount of copper in the coils is one of the largest single factors in the life expectancy and efficiency of a welding machine.

While many other types of equipment, through use of new materials and new design, have become smaller without any sacrifice in efficiency or service life — *welding machines are an exception!*

A. O. Smith welding machines have practically twice as much costly copper in their coils as other welders . . . they offer many other outstanding additional advantages. These advantages include 1 6-hp, totally-enclosed, ball-bearing, pre-lubricated fan motor (biggest in the industry) and 18-inch, big volume fan . . . Jet-stream ventilation . . . silicone insulation . . . and 75 open circuit volts.

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Current Welding Literature

For copies of articles, write directly to publications in which they appear. A list of addresses is available on request

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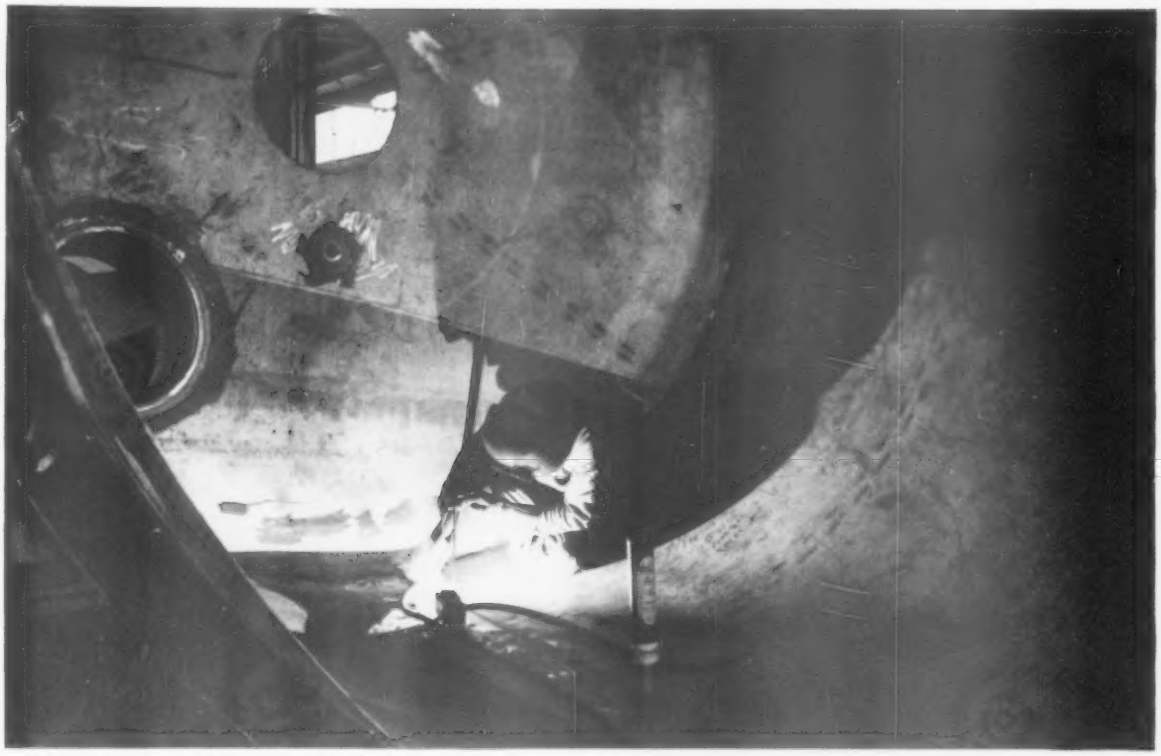

This process vessel for the chemical industry, fabricated by Colonial Iron Works, was welded with Arcaloy 309 Lime electrodes. The clad material is 304 on A 285 Grade C steel plate, 3/8" thick. Because of variances in thickness in the plate material, Mr. Weber deemed mild steel back up welding as impractical and costly, thus Arcaloy 309 Lime was used for the entire joint on all girth seams.

All nozzles are 304 stainless steel. Approximately 1200 pounds of Arcaloy 309 Lime were used for seam joints and nozzle fittings.

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ABSTRACTS OF CURRENT PATENTS

prepared by Vern Oldham

Printed copies of patents may be obtained for 25c from the Commissioner of Patents, Washington, D. C.

2,809,271—Apparatus for Selectively Forming and Welding Contacts onto Relay Parts—Robert O. Birchler, Cicero, Ill., assignor to Western Electric Co., Inc., New York, N. Y., a corporation of New York.

2,809,272—Apparatus for Selectively Forming and Welding Contacts onto Wire Spring Relay Parts—Robert O. Birchler, Cicero, Ill., and Robert F. Schalk, Madison, Wis., assignors to Western Electric Co., Inc., New York, N. Y., a corporation of New York.

2,809,273—Apparatus for Selectively Forming and Welding Contacts onto Electrical Components—Amos L. Quinlan, La Grange Park, Ill., and Robert F. Schalk, Madison, Wis., assignors to Western Electric Co., Inc., New York, N. Y., a corporation of New York.

These patents relate to specialized apparatus for welding contacts onto predetermined elements of an article. A conveyor moves the article in a predetermined path past a plurality of positions to locate successive elements of the article in a welding position. A welding mechanism is provided for welding contacts onto the elements of the article in the welding position and other means selectively render the conveyor means inoperative to stop the article in selected predetermined positions. Other means actuate the welding mechanism to effect welding action as the conveyor means are stopped.

2,809,275—Method of Manufacturing Stud-Welding Cartridges and Method of Welding—Paul Christiaan van der Willigen, Eindhoven, Netherlands, assignor, by mesne assignments, to North American Philips Co., Inc., New York, N. Y., a corporation of Delaware.

Willigen's novel method is for uniting the end of a stud-like metal object to a metal surface. The method includes positioning a heat deformable, slag-forming object between the end of the stud-like metal object and the metal surface. Pressure is exerted on the stud-like object in the direction towards the metal surface and an arc is ignited between the stud-like object and the metal surface to cause the heat-deformable, slag-forming object to be deformed and then the end of the stud-like object is moved into uniting engagement with the metal surface.

2,809,276—Process of Welding Tubes to Plates—David T. Smith, Chicago, Ill., assignor to International Harvester Co., a corporation of New Jersey.

Smith's process is for welding tubing to sheet metal and initially a tube is placed on a flat sheet. This tube has an eccentrically positioned passage therein and has relatively thick lower and side wall portions. The side walls are positioned substantially perpendicular to the sheet and a first flat wheel electrode is applied to the surface of the sheet opposite the tube. A second wheel electrode curved to engage with the tube is engaged with the upper surface thereof and pressure is applied to the electrodes simultaneously with electrical current so that during relative movement of the electrodes, tube and sheet, the tube is welded to the sheet.

2,809,277—Magnetically-Impelled Arc Welding Method and Apparatus—Rudolph Thomas Breymeier, Oak Ridge, Tenn., assignor to Union Carbide Corp., a corporation of New York.

The patented method is for fusing thin metallic workpieces together and an elongated nonconsumable stationary electrode is connected in series with an electric power source and the work piece and has its lower end positioned above and parallel to the seam to be fused. An arc is formed and is subjected to the influence of a transverse magnetic field moving in the direction of seam to be fused to impel the arc between the electrode and workpiece along the seam. Concurrently the arc and the workpiece are shielded from the atmosphere.

2,809,278—Method and Apparatus for Magnetically-Impelled Arc Welding—John A. Persson, Kenmore, N. Y., assignor to Union Carbide Corp., a corporation of New York.

The present patent is on a method very similar to that of Patent No. 2,809,277, but particularly relates to the provision of stationary field windings in the apparatus for setting up a magnetic field transverse to the arc and traveling in the direction of the seam to be fused.

2,809,280—Automatic Welding Device—Paul Christiaan van der Willigen, Nicolaas Sjoerd Theodorus Feldberg and Gerardus Otten, Emmasingel, Eindhoven, Netherlands, assignors, by mesne assignments, to North American Philips Co., Inc., New York, N. Y., a corporation of Delaware.

The patented device is for use in a protective gaseous atmosphere and includes a motor, means connected to the motor for conveying welding wire to the workpiece and including at least one disengageable clutch. A switch is operatively connected to the clutch and the welding current circuit so that upon engagement of the clutch the circuit is completed for supplying welding current to the wire.

2,809,423—Salt Flux and Method for Brazing Aluminum Parts Therewith—Dean K. Hanink, Birmingham, Mich., assignor to General Motors Corp., Detroit, Mich., a corporation of Delaware.

By the method of this patent, a thin sheet made of aluminum or aluminum alloys is positioned between parts having aluminum or aluminum base-alloy surfaces and the parts and sheet are immersed in a fused salt bath maintained at a temperature between about 1110 and 1150° F. The salt bath is primarily made from sodium chloride, potassium chloride, barium chloride, cryolite and aluminum fluoride.

2,810,062—Welding Apparatus—Clyde F. Kaunitz, Bay City, Mich.

Kaunitz' apparatus relates to a welding machine having rapid weld follow-up characteristics. Included in the patented apparatus is a control cylinder and piston and slide means for supporting a movable electrode. The operation of the cylinder and associated means is such that the electrode will follow up the receding work surface as the surface softens under the heat generated by the welding current.

2,810,063—Welding Apparatus—Turner G. Brashear, Jr., El Cerrito, Calif., assignor to American Brake Shoe Co., New York, N. Y., a corporation of Delaware.

By the patented process, a line of high resistance blanket flux is deposited along the work to be welded and a welding wire is advanced endwise into such flux blanket. Welding current across the work and welding wire produce an arc therebetween and a magnetic field about the welding wire which is provided with relative movement with relation to the work and parallel to the elongated blanket of flux. An excess of magnetizable alloying flux is supplied to a portion of the magnetic field spaced from the work to form an initial sleeve of alloying flux about the advancing wire, and outer portions of such initial sleeve are displaced to limit the thickness thereof and provide a final flux sleeve of predetermined thickness.

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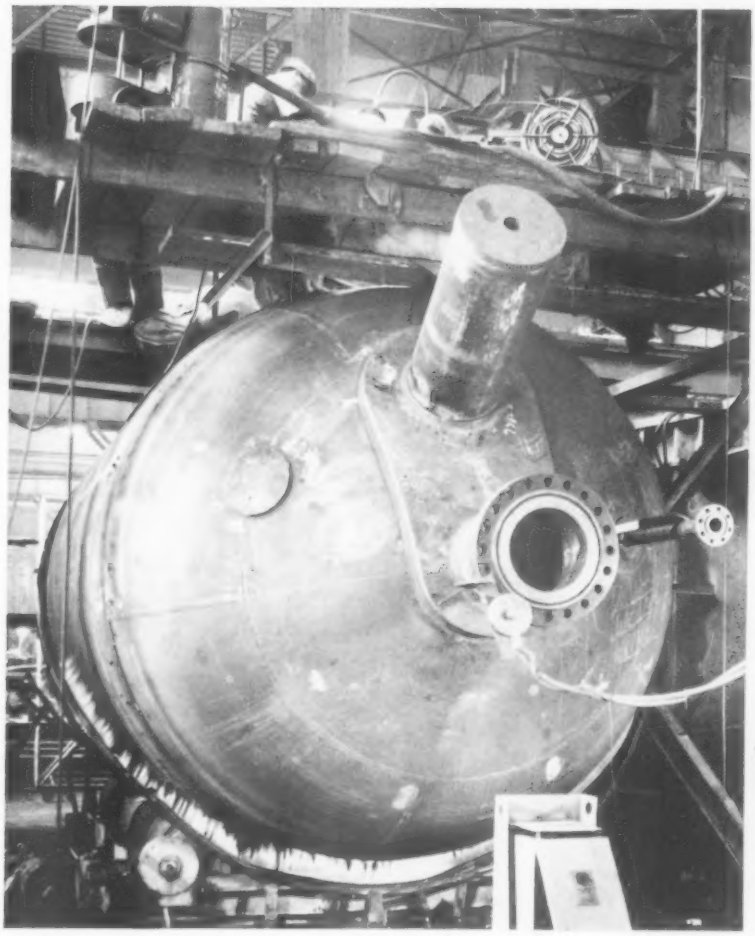

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NEWS of The Industry

Lukens to Market Plate-Mate Electrodes

Lukens Steel Co. has officially entered the electrode industry. The 148-yr old firm, with headquarters in Coatesville, Pa., arrived at the decision after considerable research, not only on the welding electrodes themselves but also in the available market within the industry. According to J. F. Wiese, vice president-commercial, the steel-plate company felt that there would be room for another electrode producer in this competitive field. Mr. Wiese pointed out that 650 million lb of electrodes were shipped in 1957 from 18 companies and at a total billing of $150 million.

Lukens' electrodes will be sold on a direct mill-to-user basis and all wires will be designed specifically to weld the many types of plate rolled by the Coatesville firm. All wires will be sold under the trade name, "Plate Mate."

William Kelly, electrode sales manager, emphasized that prices of "Plate Mate" electrodes will be competitive. Mr. Kelly also said that the 97 new Plate-Mate electrodes can be classified in 6 general categories. Lukens will produce the following types of electrodes: 34 stainless-steel, 24 low-hydrogen, 14 mild steel and 11 low-hydrogen iron-powder; in addition, 8 stainless-steel wires and 6 automatic welding wires will also be marketed.

New NCG Gas Plant

The National Cylinder Gas Division of Chemetron Corp. has started construction on a $3,000,000 liquid oxygen, nitrogen and argon plant near Philadelphia, J. L. Adank, division president, announced in Chicago.

The new plant will provide a direct pipe line supply of oxygen to be used in the new H-iron process of iron-powder production at the Alan Wood Steel Co. plant in Conshohocken, Pa. Production of oxygen is scheduled to start early in 1959. The site is adjacent to an existing NCG plant which is producing oxygen, nitrogen and acetylene.

Inventors Cited by Westinghouse

For inventions leading to the development of West-ing-arc welding systems, Westinghouse Electric Corp. has presented $9000 in patent awards to six engineers and research scientists.

At a special ceremony, W. W. Sproul, Jr., vice-president in charge of general products, presented awards. Sharing equally in recognition were Harry J. Biehsel [M'43], George H. Cotter [M'42], and Joseph F. Miller, of the Westinghouse welding department, Buffalo, N. Y.; Alfred Baeslack of the systems control department, also Buffalo; and Howard Ludwig [M'42] and Julius Heuschkel [M'45], of the company's research laboratories at Pittsburgh.

Development of the West-ing-arc welding system dates back to the mid-1940's and includes the combined efforts of all six inventors. The six-man team developed a new integrated welding system that introduced oxygen into the inert-gas atmosphere surrounding the arc to stabilize the melting of the electrode metal. Other patents in the system deal with new electrode core materials, an advanced power supply unit, a mechanism to drive the electrode and a new welding gun.

Fifth Nuclear Congress

Preliminary plans for the Fifth Nuclear Congress to be held in Cleveland, Ohio, in April of 1959, were announced today by Engineers Joint Council. At the same time, engineers and scientists who would like to present technical papers during the Congress were invited to submit outlines before Oct. 1, 1958.

As in the past the Congress will be composed of four parts: The Nuclear Engineering & Science Conference, the Hot Laboratories & Equipment Conference, the Atomic Energy Management Conference and the Atomfair at which nuclear equipment will be on display. The Congress will be held at the Cleveland Auditorium, April 5-10. The AWS will serve as one of the supporting organizations.

Authors interested in presenting papers should submit 300-500 word summaries of their articles to the National Secretary prior to Oct. 1, 1958.

DIGNITARIES TOUR HOME BUILDING SHOW

Interrupting their tour of exhibits at the Miami County Home Building Show for a brief conversation are (*left to right*) O. S. Metcalf, mayor of Troy, Ohio; E. A. Hobart, president of Hobart Bros. Co.; and C. William O'Neill, governor of Ohio. The governor officiated at the cutting of the ribbon that officially opened the Home Building Show at the Hobart Arena

COMING EVENTS

A Calendar of Welding Activity

AWS National Meetings

1959 Spring Meeting and Welding Show:
April 6-10, Sherman Hotel, Chicago, Ill.

ASM

October 27-31, 1958. 40th National Metal Exposition & Congress, Cleveland Public Auditorium, Cleveland, Ohio.

Midwest Welding Conference

Jan. 28-29, 1959. Illinois Institute of Technology, Chicago. Sponsored by Armour Research Foundation and AWS Chicago Section.

Fifth Nuclear Congress

April 5-10, 1959. Public Auditorium, Cleveland, Ohio

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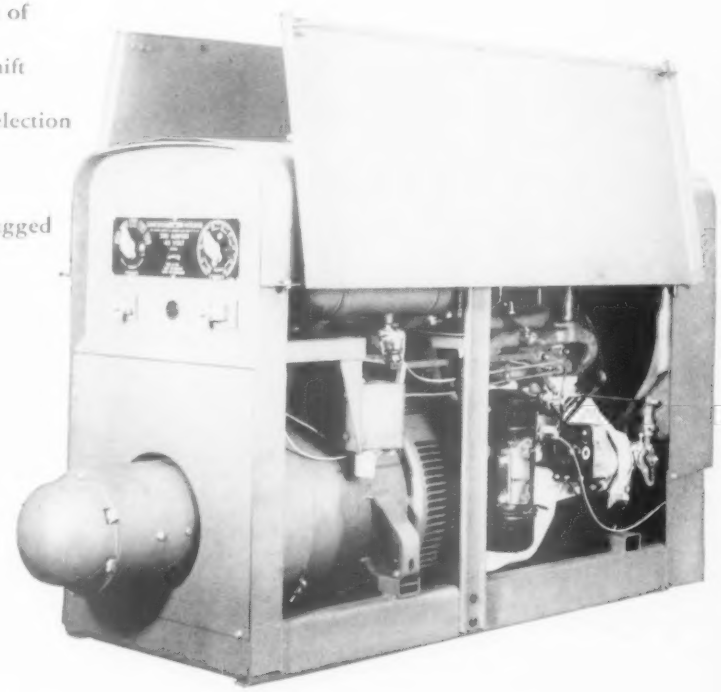

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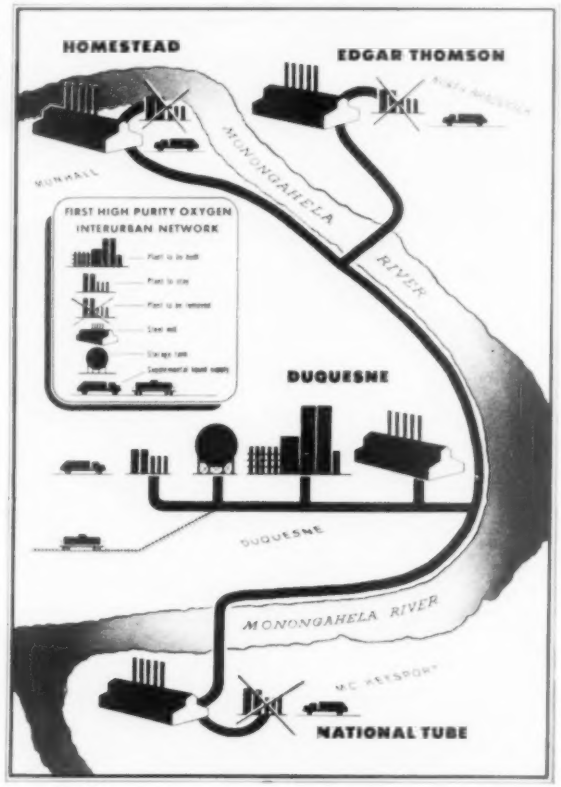
Linde to Erect and Operate Largest Oxygen-Producing Plant

The largest oxygen-producing plant in the free world is expected to go "on stream" shortly at the Duquesne Works of the United States Steel Corp. on the Monongahela River, south of Pittsburgh. To be erected and operated by Linde Co., Division of Union Carbide Corp., the new plant is expected to produce 1000 tons of 99.5% pure oxygen per day. This main plant at the Duquesne Works will also distribute oxygen through a pipe-line network to three other U. S. Steel installations, namely, Homestead, Edgar Thomson and the National Works of the National Tube Division. Provision is made for future extension of the pipe line to another location, Carrie Furnaces. The new plant will replace Linde's oxygen capacity already installed at Homestead, Edgar Thomson and National Works. Linde officials point that about 200 cu ft of oxygen are used in every ton of ingot steel produced and that even greater amounts are predicted for steel making in the future. In the past, half of a steel mill's oxygen consumption has been used in such practices as scarfing, cutting and scrap preparation.

A map of the area depicts U. S. Steel's plans for their new oxygen plant near Pittsburgh



French Group Announces Competition

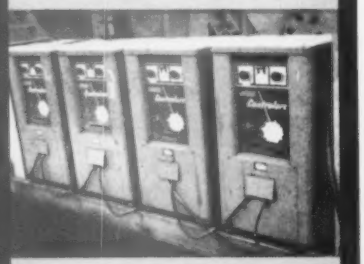
The Commission Permanente Internationale, Paris, France, has announced a Third International Competition for papers dealing with one or more practical applications of the oxyacetylene flame. Prizes will be awarded to the best papers in the competition for the calendar year of 1959. Interested authors are urged to write for further details to International Acetylene Association, 30 E. 42nd St., New York 17, N. Y.

Chemetron New Official Name

Official approval by the stockholders of the previously proposed change of the name from National Cylinder Gas Co. to Chemetron Corp. was voted at the firm's annual meeting on May 6th in Chicago. The stockholders authorized the adoption of a resolution amending the certificate of incorporation.

The seven divisions of Chemetron Corp. will now be known as National Cylinder Gas, Tube Turns, Pennsylvania Forge, Perforating Guns Atlas, Girdler Construction, Girdler Process Equipment and Chemical Products.

This 70-foot towboat, and two 120-foot boats, were constructed in stainless steel from the main deck down, for service at U. S. Steel Corporation Clairton Works, Pittsburgh.



Some of the 20 Vickers Controlarc welders in service at St. Louis Shipbuilding and Steel Co.

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Vickers Controlarc DC Welders played an important part in an unusual project by St. Louis Shipbuilding and Steel Company: the construction of the first inland waterway towboats with stainless steel hulls. The three boats were built for service on the Ohio and Monongahela Rivers at U. S. Steel Corporation's Clairton Works, Pittsburgh.

A big feature of the Controlarcs' performance on this job was elimination of stub loss on stainless steel electrodes by *automatic* maintenance of a constant current setting from arc strike to end of pass. With a ton and a half of costly electrodes used on the 10,500 feet of welding, dollar savings were appreciable.

Suitability of the Controlarc for Arcair gauging and cutting was another reason for the choice of this machine.

For better performance on *any* welding job, the Vickers Controlarc magnetic amplifier-rectifier DC Welder provides automatic control of *current* and *type* of arc adaptable to changes in welding conditions. For complete information on this unusual welding machine, write today for Bulletins EPD 7116-1.

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INTERNATIONAL WELDING NEWS

By Dr. Gerard E. Claussen

Welding Education Program Adopted

The Swiss Welding Society[1] has opened its new welding school in Basel. Annual accommodations for 400 students have been provided in gas welding, 400 in arc welding and 200 in plastic welding. A total of 60 to 70 courses will be offered in weekly programs consisting of three daily and three evening courses. The school has a floor area of nearly 3000 sq ft. The rebuilt welding school of the German Welding Society,[2] cooperating with the city of Duisburg, was opened in February 1958. The city gave 73,000 sq ft of land for the school, which is used for instruction in arc and gas welding. The photographs of the school depict excellent facilities for instruction.

A participant[3] in the welding engineer's course of the Mannheim Welding Institute in Germany has described the course of instruction and the examination. For six weeks, 9 hours a day, the 16 students listened to lectures by twenty experts, mainly from industry, and performed laboratory work. An applicant for the course needed the following qualifications: at least 25 years old; a technical school graduate or three years' practical experience; and a successful grade in an oral examination in general engineering. The final written examination covered materials testing, welding processes and apparatus, metallography, design and testing. Eleven of the 16 candidates passed the examination, which entitled them to be welding engineers in the sense described in German Standard DIN 4100.

Standards, Prizes and Meetings

German Standard DIN 1911, on definitions of terms in pressure and resistance welding, has been brought up to date in a revised issue.[4] The Permanent International Commission on Acetylene[5] announced its third prize contest for the best paper on the application of air- or oxyacetylene flames for welding, brazing, cutting, metallizing, etc. Entries must reach the Commission (32 Boulévard de la Chapelle, Paris, 18) before Dec. 31, 1959. Prizes will total 6000 Swiss francs. A European Committee of Arc Welding Electrode Manufacturers[6] was formed in January 1958 with headquarters at 10 avenue Hoche, Paris 8. Manufacturers in West Germany, Belgium, France, Italy and Switzerland are represented in this group. At the annual meeting of the French Society of Welding Engineers in January 1958 the new president, P. Lorin, was installed.[7] The Society has a membership of 1219, an increase of 50 over 1956. Besides monthly technical meetings in Paris and other meetings at local sections, the Society cooperated with other organizations and awarded prizes to worthy students at welding schools in France. The annual dues were increased.

Russian Mechanization

A set of six papers[8] on mechanized welding appeared in the Russian welding monthly. The papers covered mechanization in several fields: heavy machinery, pressure vessels, shipyards, large diameter pipe and pipe lines. In joining lengths of pipe by flash welding, the platen movement was proportional to the square of the time after the start of welding. One paper illustrated a submerged-arc welding machine for joining lengths of pipe in the overhead position. Nikolajew[9] describes the erection of storage tanks using, for the sidewall, a roll of welded plate the full height of the tank. He also illustrates Russian inert-arc pull guns with small spools of wire, and single and multiple electrode guns for circumferential welding of pipes using CO_2. A conference[10] on automatic welding in the Czech machinery and railway shops was held in October 1957. Of the welding involved in railway car construction, 70 to 92% was automatic.

Arc Welding in Holland

A method of welding steel plates in the vertical position with covered electrodes but without edge preparation has been in use in a Shell plant in the

ICELANDIC WELDERS TRAIN AT LINCOLN SCHOOL

Students from Iceland at Lincoln Electric's Welding School in Cleveland are shown in the midst of their 9-week course in arc welding. Pictured standing (*left to right*) are Thormar Gudjonsson, Thorir Gudjonsson, Gudmundur Gudmundsson, Fridrik Sigurbjornsson, Sverrir Olsen and Eirirkur Gudmundsson. Lincoln instructors Fred Klein and Clifford Fulton are in the foreground. The students attended the school under the auspices of the U. S. Government's Foreign Operations Administration

Dr. Gerard E. Claussen is associated with the Linde Co., Newark, N. J.

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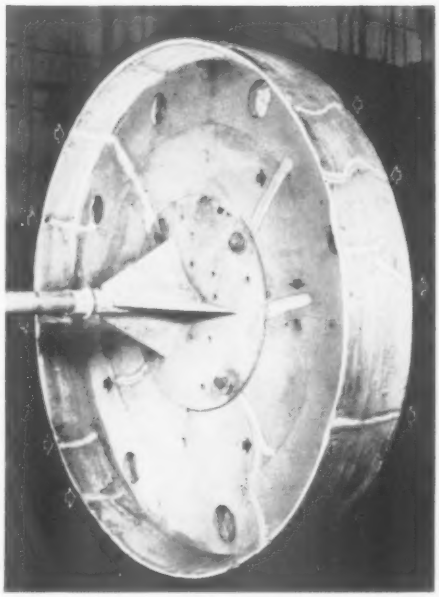
5 MONTH "DOWN TIME" AVOIDED... COSTS CUT 66%



This pulverizer intermediate ring, used by a cement company, cracked in operation. Replacement posed a difficult and time consuming problem. Obtaining a new ring would have kept the pulverizer out of operation for at least five months.

In spite of the fact that the ring rotates at high speeds and is subject to the shock of impact from heavy steel balls bouncing around and abrasive wear while grinding shale, it was decided to try welding the damaged part.

One of the special problems in connection with repair was that the ring was made of alloy steel and cutting out the cracks became a special job in itself. A cutting torch did not remove metal quickly enough and the high heat involved had a tendency to cause additional cracks and fissures. Grinding wheels were considered, but this would have taken a great deal of time and the tough alloy steel raised havoc with these grinding wheels.

A special oxygenless cutting electrode ChamferTrode was used to gouge out the cracks. This method resulted in extremely rapid removal of the unwanted metal in the area to be welded.

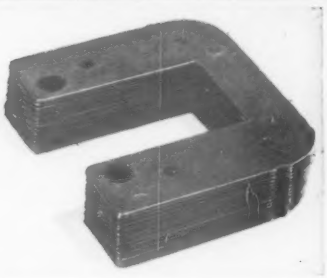
EutecTrode 680 AC-DC was used for the filling operation. This is an extra-high strength, Low Amp electrode, used where embrittlement must be avoided. It provides an ideal hard overlay cushion. EutecTrode 680 AC-DC permits quality welding on pressure vessels, dies, tools and has also seen wide use in rebuilding chemical agitator blades and shafts.

EutecTrode 680 AC-DC also has a "Frigid-Arc" coating — allows smooth, porosity-free dense deposits without spatter, and with exceptional freedom from cracking. Welds are easily deposited at the highest possible speed with least amount of base metal heat, using lowest possible amperage. The ultimate tensile strength, up to 120,000 psi.

Once the pulverizer ring was prepared and readied, weld deposits were completed, then ground flush with the rest of the ring. The mill was then put back into continuous operation with the repaired ring and has operated perfectly in spite of the heavy continuous punishment this part receives.

Materials for the repair were less than 1/5 the replacement cost, and the mill was back in full production in less than three days.

EUTEC-SILWELD 1618 PROVIDES SILVER LINING



A substantial saving was made by a transformer fabricator in laminating coils with paste-on form, silver content alloy, Eutec-Silweld 1618. The paste form eliminated unnecessary handling and waste in replacement of solder strip, and proved considerably faster in application.

Production of Eutec-Silweld 1618 in paste form partially explained its lower heat input. The minute silver particles suspended in flux melt and flow faster than solid silver. It joins at heat input as much as 150°F. less than required for conventional silver brazing material, and the lowest heat range possible for silver content alloys.

In this transformer application, the unusually low bonding temperature with Eutec-Silweld 1618 not only foreshortened induction heat cycle time, but virtually eliminated rejects caused by conventional high heat welding materials.

EutecTrode 680 AC-DC, available in 3/32", 1/8", 5/32", & 3/16" dia. Lt. Blue Tip. Standard weight shipments. • **Eutec-Silweld 1618,** packaged in 8 oz., 1 & 2 lb. jars.

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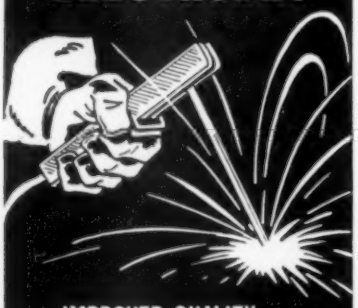

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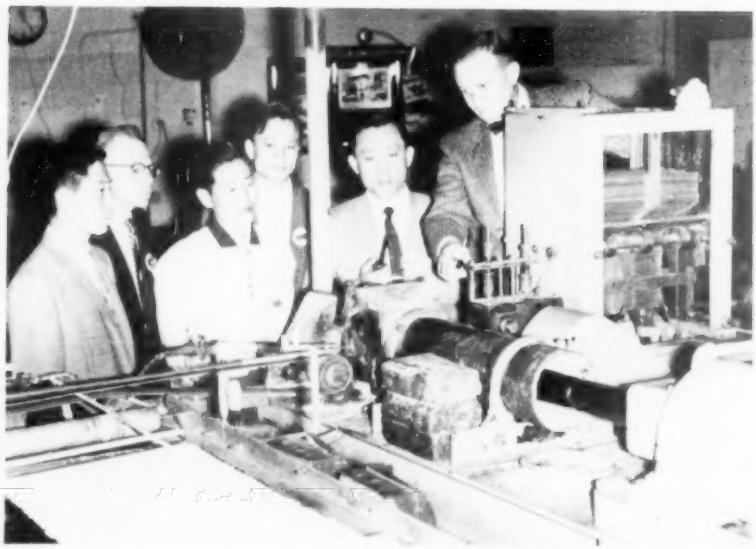
KOREAN ENGINEERS TOUR EUTECTIC PLANT



An exchange program sponsored by the State Department brought several Korean engineers to Eutectic Welding Alloys Corp.'s, Flushing, N. Y. plant where they inspected (above) part of a highly mechanized and automatic electrode coating and feeding apparatus. Shown viewing the operation are (*left to right*) Sang Yool Moon, Department of Labor representative John Brennan, Hi Chun Joo, Hak Kin Kim, Jin Kyun Park and Harley Erickson, production manager of Eutectic

Netherlands for many years.[11] For plates $\frac{1}{4}$ to $\frac{3}{4}$ in. thick the spacing is up to $\frac{1}{2}$ in. An operator welds on each side of the joint. The first operator welds half his electrode before the other operator starts. Both use $\frac{5}{32}$- or $\frac{3}{32}$-in. electrodes. The second operator continues while the first is changing electrodes. The slag comes to the outer surface of the weld. For plates over $\frac{3}{4}$ in. thick, $\frac{3}{32}$- or $\frac{1}{8}$-in. electrodes are used, and the operators work in the same puddle, moving their electrodes in and out. The welds have excellent mechanical properties. Low-hydrogen electrodes and ac must be used—and the heat-affected zone becomes overheated. However, there is no angular distortion, high arc time, no slag chipping and no root tacks or defects.

French Study Penetration

The French Institute of Welding[12] has made a statistical study of penetration using several makes of deep-penetration covered electrodes. A linear formula for penetration was preferred to exponential formulas for relating penetration (mm) to current (I, amp), voltage (V) and electrode diameter (D, mm):

$P = 0.045I - 0.13V - 0.16D + 1.3$ for electrode 1

$P = 0.041I - 0.18V - 2.2D + 9.2$ for electrode 3

Plate thickness and plate temperature had little influence on penetration. Maximum penetration was obtained at an arc length characteristic of each electrode; for example, 0.28 in. at 54-57 v, 0.24 in. at 51 or 59 v, for a $\frac{5}{32}$-in. electrode at 235 amp and 12 ipm travel speed, 0.04 in. gap between unbeveled plates.

New Russian Electrode

Russian writers[13] describe the development of a covered electrode for welding creep-resistant steel:

	Plate	*Weld*
C, %	0.12	0.15
Si, %	0.14	Trace
Mn, %	0.51	0.29
Cr, %	11.80	10.65
Ni, %		0.94
Mo, %	0.89	1.13
W, %	1.90	1.09
V, %	0.38	0.25
S, %	0.021	0.009
P, %	0.027	0.018

The weld metal had the following short-time properties at 68 and 1112° F after 7 hr at 1350° F.

	68° F	*1112° F*
Yield strength, psi	97,000	56,000
Tensile strength, psi	120,000	61,000
Elongation %, in 2 in.	54	78
Notch impact value, mkg/cm²	8.5	15.2

The creep strength at 1130° F for 100,000 hr was 14,200 psi, although this

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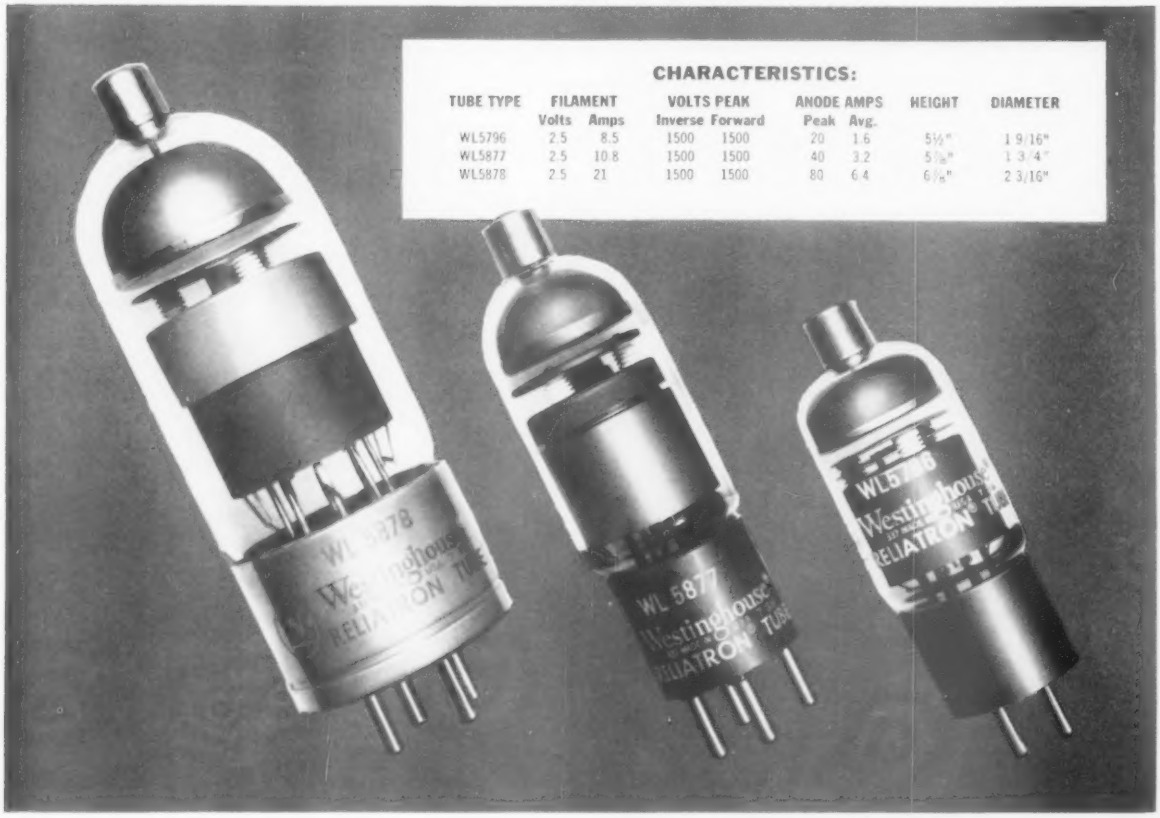
CHARACTERISTICS:
TUBE TYPE | FILAMENT Volts Amps | VOLTS PEAK Inverse Forward | ANODE AMPS Peak Avg. | HEIGHT | DIAMETER
WL5796 | 2.5 8.5 | 1500 1500 | 20 1.6 | 5½" | 1 9/16"
WL5877 | 2.5 10.8 | 1500 1500 | 40 3.2 | 5⅞" | 1 3/4"
WL5878 | 2.5 21 | 1500 1500 | 80 6.4 | 6⅛" | 2 3/16"
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Westinghouse Type	Replacement For
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WL5877	5544, 730
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seems to have been extrapolated from a 2500-hr result of 20,000 psi. Corrosion resistance was satisfactory in air and steam at 1200° F. Weld metal containing 0.08% carbon contained ferrite and had poor impact value at and below +122° F. The nickel content and the 0.15% carbon eliminated ferrite. Without vanadium the creep strength fell to 5700 psi at 1130° F.

Welded Bridges at Le Havre

Two all-welded swing bridges,[14] each of 121-ft span, have been erected at Le Havre, France. Deep penetration electrodes were used to minimize residual stresses. The inspection service and port engineers allowed the use of deep penetration in designing fillet welds, so that relatively small amounts of weld metal were permissible. Radiographic inspection showed that 95% of the inspected welds were perfect. The faulty 5% had small defects which were easily repaired.

An investigation was made by a Russian writer[15] of transverse cold cracks across the weld and heat-affected zone of inert-gas welds in titanium and its alloys. He used a slotted disk as a dilatometer to measure changes in volume during cooling after welding. The increase in volume at the beta-to-alpha transition on cooling was intensified with increase in hydrogen content of the metal. For example, as the hydrogen was increased from 0.016 to 0.089 weight percent, the strain increased from 200 to 900 microns in the disk. The increased deformation was believed due to precipitation of titanium hydride. An increase in the nitrogen and oxygen content of the metal promoted cracking by lowering the ductility of the metal.

Russians Examine Spot Welding

Comparing spot welding with riveting for aluminum alloys in aircraft, Russian writers[16] concluded that spot welds have the edge economically. Tests showed spot welds in Alclad to have the same static and fatigue strengths as rivets. Under repeated static load, spot welds had slightly lower endurance than rivets. Sheet-to-profile spot welds had 25% higher static strength than sheet-to-sheet spot welds.

Calculations and measurements were made by a Russian writer[17] of the distribution of current and temperature across the wall thickness of pipes during the resistance roll welding of longitudinal seams. The author recommends that the distance D between the electrode wheels should vary with wall thickness T as follows:

T, in.	D, in.
0.04-0.08	0.12-0.16
0.10-0.24	0.20-0.24
Over 0.24	$D = T$

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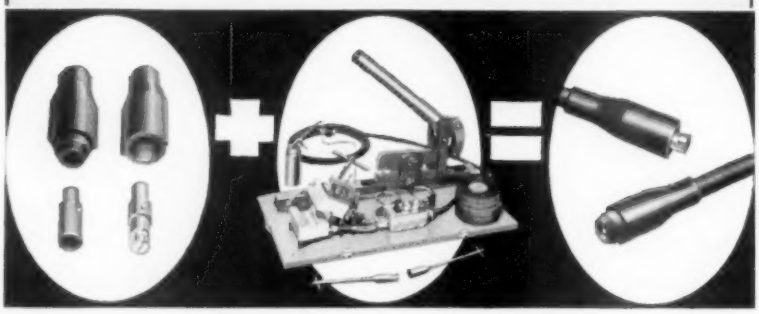

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To insure arc ignition in stud welding, Vaniboim[18] passes a preliminary direct current of 15 amp for 0.1 sec. This causes a low-current arc to form, which assures ignition of the main 900-amp stud-welding arc. The auxiliary arc prevents freezing of the electrode and, due to inductance, is very stable. The end of the ¼-in. diam mild-steel stud is ground to a 90- to 120-deg cone with a flat top 0.024-0.032 in. in diameter, which must be clean.

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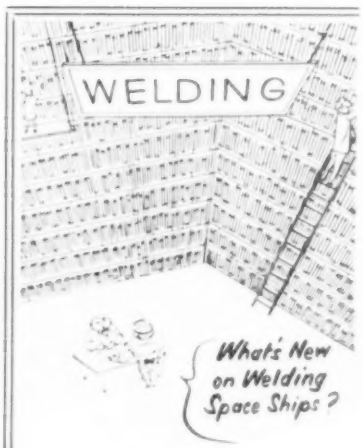

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PERSONNEL

Fisher Joins Aronson

Aronson Machine Co., Arcade, N. Y., announces the appointment of William L. Fisher AWS to the position of Eastern District Sales Manager.

W. L. Fisher

Mr. Fisher has had 25 years' experience in the welding field, 17 of them spent in Philadelphia and the last 8 years as sales manager of a welding equipment firm in Pittsburgh.

Smith Elected President

Knowles B. Smith AWS, executive vice-president of Dix Engineering Co., Inc., 1415 Dix Rd., Lincoln Park, Mich., has been elected president of the Metco System Contractors.

K. B. Smith

Mr. Smith's election occurred at the recent annual meeting of the Metco group in St. Louis, held concurrently with the annual meeting of the American Welding Society.

Metco System Contractors is a national organization of firms specifically engaged in metallizing and combination plastic protective coatings for corrosion and erosion control. The group was formed in 1949 to set up industry-wide standards and practices.

DeLisi and Guerin Named

Paul Galton AWS, manager of Plainfield Division sales, Worthington Corp., Plainfield, N. J., has announced the appointment of Paul F. DeLisi AWS and Gerald A. Guerin as positioning equipment distribution supervisors. According to Mr. Galton, both men will work with distributors to promote sales of positioning equipment. Mr. DeLisi will supervise sales in Worthington's Eastern Region which includes the Newark, New York, Boston, Philadelphia, Washington, D. C. and Atlanta District offices. Mr. Guerin will supervise the Mid-Western Region, covering district offices in Chicago-Milwaukee, St. Louis, Kansas City, Minneapolis and Denver.

Fogarty Joins Tube Turns

Appointment of Richard H. Fogarty AWS as pipe welding engineer has been announced by the Tube Turns Division of Chemetron Corp.

R. H. Fogarty

Mr. Fogarty will headquarter in New York and work with contractors, engineers and users of industrial piping in the solution of welded piping problems, and will be associated with the firm's established field program for training qualified pipe welders.

Mr. Fogarty, active in the piping industry since 1940, has had extensive teaching experience in Philadelphia at Mastbaum Evening School and at Dobbins Vocational School, where he was an instructor in apprentice training courses.

Hunt Named by Airco

K. H. Hunt, formerly superintendent of Air Reduction's new $7,500,000 Chicago liquid oxygen, nitrogen and argon plant, has been appointed works manager of the plant, it was announced by George M. O'Neil, regional production and distribution manager. Mr. Hunt succeeds W. F. Grotevent who has been transferred to the eastern region to manage a similar plant now being completed near Boston, Mass.

Starting with Airco in 1933 at Chicago, Mr. Hunt has held various positions, rising to assistant regional production manager in 1953 and becoming superintendent of the Chicago liquid plant last year.

Burns Named by G.E.

The appointment of Gordon E. Burns of Chicago as distributor sales manager of General Electric's receiving tube and electronic components replacement business has been announced.

Mr. Burns will plan and direct sales policies and activities for G.E.'s network of sales offices from his new location in Owensboro, Ky.

Voloshin Appointed by L. A. Firm

Norberto Voloshin AWS has been named chief engineer at Hirt Combustion Engineers, Los Angeles, Calif., General Manager John H. Hirt has announced.

Prior to joining Hirt Combustion Engineers, Mr. Voloshin was design engineer in the Industrial Heating Division of Westinghouse Electric Co., Pennsylvania. Previously he was an instructor in physics and metallurgy at the University of Buenos Aires and holds a degree in industrial engineering from that institution.

He is a member of the American Society for Metals.

OBITUARY

Philip W. Swain

Philip W. Swain, former editor of *Power* magazine, a McGraw-Hill publication, died at his home in Riverside, Conn., on April 27th. He was 68 years old.

Active with AWS throughout his

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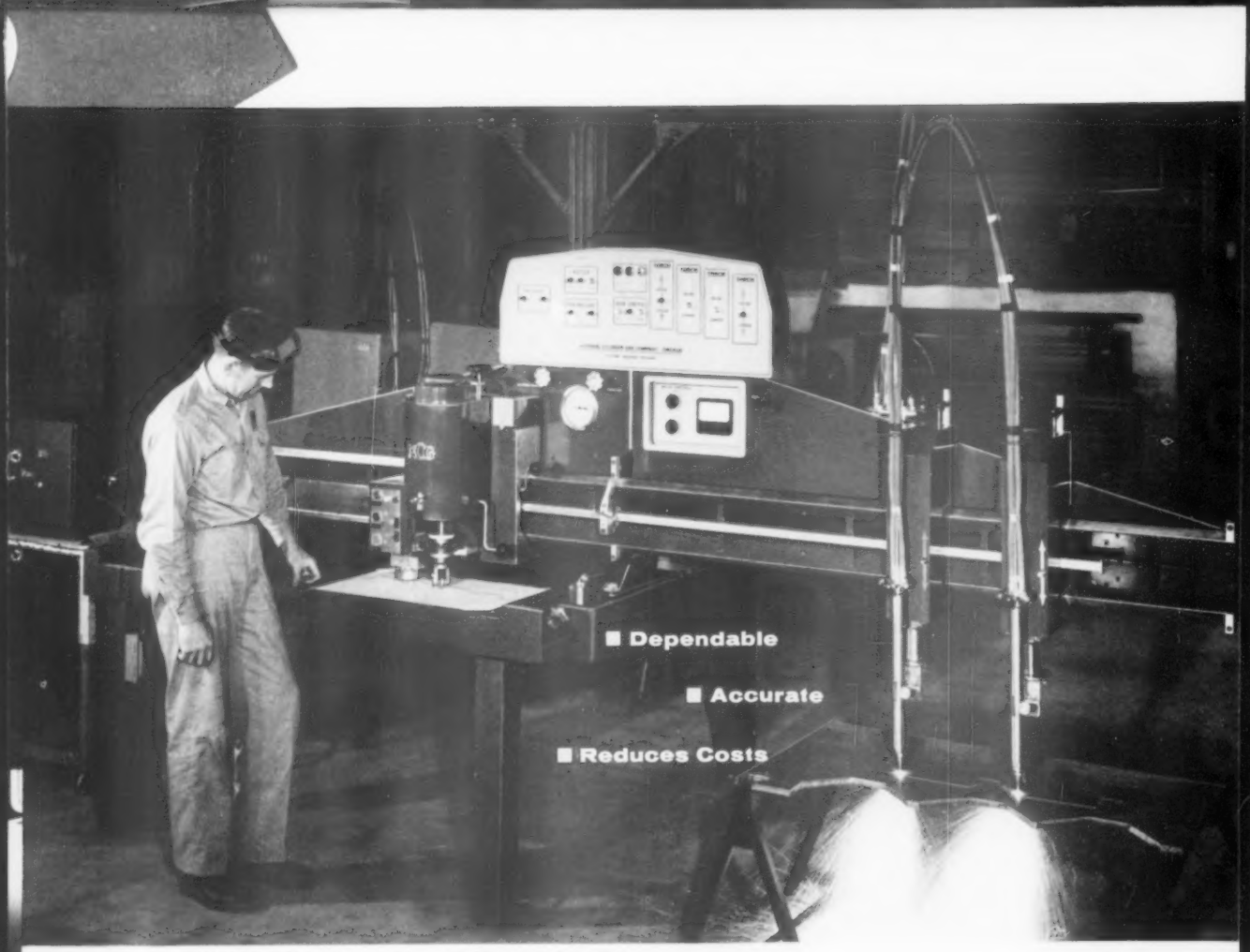
NCG Electronic Line Tracer in operation accurately following a pencil drawing. The gear cover has been removed to show the drive assembly.

For more details, circle No. 29 on Reader Information Card



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4 The NCG Electronic Line Tracer operates with ease. Manual steering directs the tracing head to the line of the drawing . . . the head follows a straight path until the line is intercepted, then the line tracer scanning system will automatically follow the line drawing.

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career, Mr. Swain was a graduate of Syracuse University and obtained his technical training at the Sheffield School, Yale University. He later taught thermodynamics at Sheffield and journalism at Columbia.

Mr. Swain joined *Power* in 1921 as an associate editor and became editor in 1934. Since his retirement from *Power* in 1954, Mr. Swain was consulting editor of the magazine. At the time of his death he was head of the advisory council of Stoetzel and Associates, a Chicago marketing and advertising firm.

Vsevolod N. Krivobok

Dr. Vsevolod N. Krivobok, well-known authority on stainless steels and supervisor of the Stainless Steel and Heat-Resistant Alloy Section of the Development and Research Division of The International Nickel Co., Inc., died May 18, 1958, at St. Luke's Hospital after a brief illness. He was 65 years old.

V. N. Krivobok

Born in Poltava, Russia, Dr. Krivobok was a naturalized United States citizen. A graduate of St. Petersburg, Russia, Polytechnic Institute, he attended Harvard University where he received a SB degree in Metallurgy in 1921, degree of Metallurgical Engineer in 1922, and Doctor of Science degree in 1924.

Prior to joining International Nickel's Development and Research Division in New York in 1944, Dr. Krivobok had been Director of Research and Chief Metallurgist of Lockheed Aircraft Corp. at Burbank, Calif., since 1941. He was a member of the faculty and Professor of Metallurgy at Carnegie Institute of Technology, Pittsburgh, Pa., from 1924 to 1940, while also serving as Associate Director of Research for the Allegheny Ludlum Steel Corp., Brackenridge, Pa. (1934–41). From 1924 to 1934, Dr. Krivobok was a member of the Metallurgical Research Bureau of the Carnegie Institute of Technology.

In 1934 Dr. Krivobok was the Campbell Memorial Lecturer for the American Society for Metals, and presented the Sauveur Memorial Lectures for this society in 1939 and 1943. Dr. Krivobok was chairman of the High Alloys Committee of the Welding Research Council, a retired Trustee and member of the American Society for Metals, and a member of the American Welding Society, American Institute of Mining, Metallurgical, and Petroleum Engineers, American Society for Testing Materials, British Iron and Steel Institute and the British Institute of Metals.

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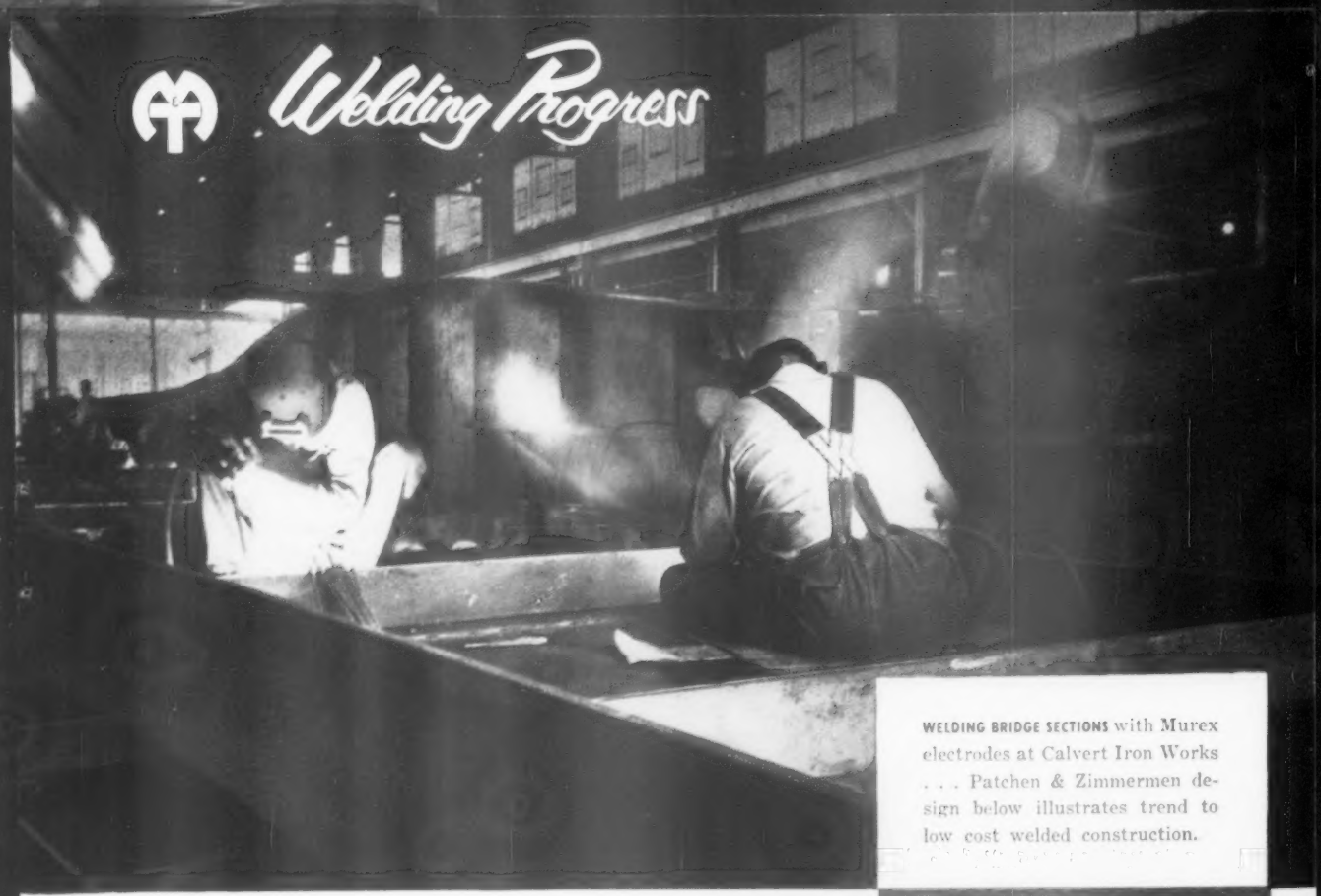
Positions offering unusual professional growth opportunities with expanding Atomic Energy Division of long established manufacturer of power generating equipment. Minimum requirements—degree plus experience in practical metallurgy and fabrication of carbon and stainless steels. Knowledge of fuel element fabrication and or other metallurgical and fabricational applications peculiar to atomic power generation desirable but not essential.

Send resume & salary requirements to Manager, Employee Services

ALCO PRODUCTS, INCORPORATED
SCHENECTADY 5, NEW YORK



WELDING BRIDGE SECTIONS with Murex electrodes at Calvert Iron Works . . . Patchen & Zimmermen design below illustrates trend to low cost welded construction.

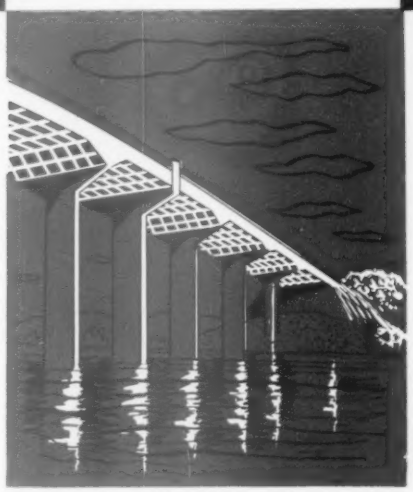
Welding Bridges with *MUREX*® Electrodes Cuts Costs

• Time-saving techniques and substantial savings in welding costs have helped Calvert Iron Works to become one of the leading bridge builders in the Southeastern Area. Here's what they say about their use of welding in bridge construction:

"Welding offers substantial savings as compared with riveted construction."

On selecting electrodes for bridge welding, they say, "Metal & Thermit's Murex electrodes not only work faster, but also give us an ideal weld. X-ray rejects have been practically eliminated. We consider Murex electrodes to be the best available for the type of bridge welding we do."

Calvert, which does in excess of ½ million feet of bridge and structural steel welding each year, practices good buying economy too — 90% of their electrodes carry the Murex label, since the Metal & Thermit line of electrodes meets their arc welding requirements, and simplifies compliance with engineers' welding specifications.



Whether you join thin sheet or heavy sections . . . there is a large selection from M&T's line of Murex mild steel, low hydrogen, iron powder, hard surfacing, and stainless electrodes that can simplify your welding operation. *Write for your copy of the M&T Selector — an easy reference for finding the correct electrode for any application.*

METAL & THERMIT
CORPORATION
GENERAL OFFICES: RAHWAY, NEW JERSEY

For more details, Circle No. 33 on Reader Information Card

H. F. Reinhard

Herbert F. Reinhard, long associated with the Linde Co., died suddenly on May 23rd.

Born in Portland, Ind., Mr. Reinhard graduated in 1921 with a BS degree in

H. F. Reinhard

Chemistry from Purdue University. After serving as a chemist with the Indiana State Board of Health, he joined the Prest-O-Lite Co., Inc., in 1923. In 1926 he was made chief engineer of J. B. Colt Co., another subsidiary of the Union Carbide Corp. Mr. Reinhard was transferred to the general offices in 1931 and was named manager of the Safety Codes Department of Linde in 1945.

At the time of his death Mr. Reinhard was in his 27th year as Secretary of the International Acetylene Association. The National Safety Council presented him with the Distinguished Service to Safety Award in 1955 and in March of this year he participated in President Eisenhower's Conference on Occupational Safety in Washington. A member of the AMERICAN WELDING SOCIETY, Mr. Reinhard was chairman of the AWS Committee on Safety Recommendations.

Forrest W. MacDonald

Forrest W. MacDonald, 40, advertising assistant, Air Reduction Sales Co., and editor of "Airco in the News," the company's external house magazine, died suddenly on Saturday, May 10, 1958. He was vice-chairman of the International Acetylene Association's Publicity Committee.

Mr. MacDonald had an AB degree in journalism from the University of California, from where he graduated in 1942. From 1942 to 1946 he was in the Service Command of the U. S. Air Corps and served many months overseas. In 1948 he enrolled at Columbia University, graduating in 1951 with an AM degree in English. He joined Airco in 1951.

EMPLOYMENT SERVICE BULLETIN

Services Available

A-706 Welding Supervisor. Craft coordinator. Twenty-nine years in welding and related activities. Last 17 in supervisor, inspection and coordination of crafts. Twelve years overseas major companies. Heavy code experience, hi-temp. and pressure, high and low-alloy piping and vessels. Many processes. High and trade school graduate. Some formal English and Metallurgical education. Knowledge Spanish. Prefer position in nuclear or missile field. Can assume heavy responsibility. Family man, good habits. Will relocate or travel.

For more details, circle No. 34 on Reader Information Card

WELDING RESEARCH

A Welding or Metallurgical Engineer is required for investigations into new and challenging areas of Welding and Brazing Research. Applicant should have at least a B.S. degree and several years of experience. Our opening offers the right man an unlimited opportunity for professional growth.

This is a permanent position in an expanding midwestern industrial research organization. Here is a challenging opportunity for the creative man who desires to work on challenging and diversified research programs and in addition enjoy stimulating staff associations and an unusually pleasant working climate. Receive excellent salary and employee benefits.

If you are interested in this exceptional opportunity, send a complete resume to:

Box V-357,
The Welding Journal,
33 W. 39th St.,
New York 18, N. Y.

NEW LITERATURE

AWS Standard on Safe Practices for Inert-Gas Metal-Arc Welding

The 2nd edition of the only publication covering all aspects of safety involved in the use of inert-gas metal-arc welding has just been published by the American Welding Society. By following the simple control measures recommended in this standard, safe working conditions can be assured.

The report, titled "Recommended Safe Practices for Inert-Gas Metal-Arc Welding" is based on laboratory studies, the experience of industry to date, and an extensive review of the literature and industrial records.

All known potential hazards peculiar to the inert-gas metal-arc process are covered in the report. The findings of the reporting committee, comprising both medical and technical men, showed that no significant hazards exist from either ozone or nitrogen dioxide, and that there is no dangerous amount of radioactivity given off by thoriated-tungsten electrodes.

However, the report focuses attention on the hazard of trichlorethylene when used in the vicinity of inert-arc welding. Decomposition of trichloroethylene vapor by radiation from the welding arc produces noxious fumes including phosgene. Therefore, this chemical, often used in degreasing operations, should be so located that even minute quantities of vapor will not come in contact with the welding arc.

Also, included for the first time, are data on carbon-dioxide shielding. Carbon-dioxide shielding may create a hazard from carbon monoxide and carbon dioxide if the welder's head is in the path of the fumes or if welding is done in a confined space. Information is given on the ventilation requirements that are adequate to control this possible hazard.

The publication also outlines adequate control measures for protecting workers from ultraviolet radiation and metal fumes produced in inert-gas metal-arc welding.

This standard is available in pamphlet form at a price of $1.00. It can be obtained by writing to the American Welding Society, 33 W. 39th St., New York 18, N. Y.

Electronic Control

Bulletin SM-277 from Square D Co., 4041 N. Richards St., Milwaukee 12, Wis., describes the company's new line of non-synchronous electronic combination-welder controllers. Square D reports that increased flexibility and simplified maintenance are effected by functional breakdown of the control into individual panels for sequence timing, power supply, valve operation and contactor firing. The combination control with 600-frame contactor has provision for either 200- or 400-amp QMB fusible disconnect switch, either 3B or 5B timer, either tube or relay control of the air valve and either tube or relay firing of the ignition contactor.

For your free copy, circle No. 35 on Reader Information Card.

Automatic Welding Wires

Air Reduction Sales Co., a Division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y., has issued an 84-page Aircomatic welding wire pocket guide.

The pocket guide, Form ADC 873, presents the varieties of wire types, wire diameters and packaging data. It also contains technical information such as chemical composition, mechanical properties and operating procedures. Conformances and approvals are shown for each wire where applicable.

For your free copy, circle No. 36 on Reader Information Card.

M & T Booklet

Publication has been announced of a new 28-page brochure detailing the past and present and evaluating the future of Metal & Thermit Corp., 100 Park Ave., New York 17, N. Y. The booklet describes the various activities that the company has undertaken since its founding 50 years ago.

Among the topics treated in the publication are the company's founding, its position in industry today, the ways in which the company's products affect the lives of the public and a look into the future of the firm.

For your free copy, circle No. 37 on Reader Information Card.

Flame-Cutting Aid

A new folder, "Cut Your Flame-Cutting Costs," is available from Linde Co., Division of Union Carbide Corp., 420 Lexington Ave., New York 17, N. Y.

The 12-page folder, Form 1057, describes several ways in which quality nozzle construction and proper nozzle selection can reduce gas consumption and nozzle replacement, the primary cost factors in all flame-cutting operations. The advantages of chrome-plating and swaged construction are also described.

For your free copy, circle No. 38 on Reader Information Card.

Arc-Welding Circuits

Lenco, Inc., 350 W. Adams St., Jackson, Mo., has published a 24-page booklet on "Reducing Costs by Proper Care of Arc-Welding Circuits." This publication is written in nontechnical language, and points out many things that can be done to keep electric arc-welding circuits operating properly.

For your free copy, circle No. 39 on Reader Information Card.

Flash-Butt Welder

The Federal Machine and Welder Co., Warren, Ohio, has issued a new bulletin which describes design features, specifications, welding capacities and electrical data of the manufacturer's newly designed flash-butt welder.

For your free copy, circle No. 40 on Reader Information Card.

If you use cutting

Big News

How Engineered Oxygen Cutting Can Increase Your Profits

A new concept in cutting machine techniques may revolutionize your thinking on what can be accomplished by oxygen cutting equipment. Messer cutting machines feature a distinctive design and construction.

For Greater Accuracy

Through a completely engineered system of operation, you can now achieve new standards of accuracy in precision workmanship! This means improved production efficiency in many industries where metal-working is involved. Messer machines can SAVE YOU MANY DOLLARS.

Revolutionary Design

Relatively new in the U.S.A., Messer is the acknowledged leader in cutting machine

Messer Cutting

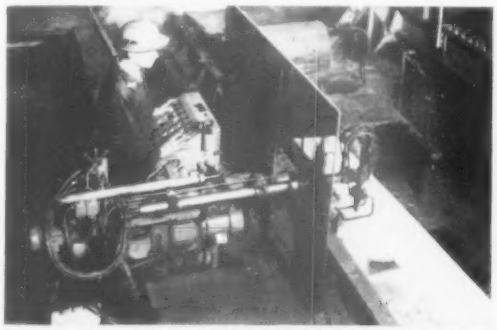
For more details, circle No. 41 on Reader Information Card.

machines, here's For YOU!

design throughout Europe and in other countries. Now in America, Messer cutting machine versatility of design permits greater shop flexibility and the increased use of automation that leads to **greater profits.**

If you use—or could use—oxygen cutting machines—it will pay you to check *now* on what Messer can offer you. Write for full information. No obligation, of course. **MESSER CUTTING MACHINES, INC., Chrysler Building, 405 Lexington Avenue, New York 17, N. Y.** *Precision Cutting Machines—Oxygen, Nitrogen, Argon Plants.*

Unlimited plate area or complex cutting operations present no problems to Messer equipment.



Complete automation is a key feature of Messer cutting machines, as used in this steel mill.

Machines

For more details, circle No. 41 on Reader Information Card.

YES! 2 ELECTRODE INVENTORY

for ALL STEEL WORK

IN STEEL You Can Be Ready for Anything! . . .

Production or Emergency Repair with ALL-STATE ELECTRODES!!! **2**

Pair up No. 275 with STEELARC.

Easiest Steel Electrode to use and nearest to a "one rod supply for mild steel welding." Enables pass on pass without wire-brushing or chipping.

Master Craftsmen say: "Weld anything in the steel field with All-State No. 275 and get highest tensile of any rod on the market.

This chromium-nickel electrode is considered by many to be their "problem-solving rod" for all steels that are normally hard to weld.

IMPORTANT FEATURES OF BOTH NO. 275 and STEELARC. Both AC-DC. Both low, low amperage—starts at 40. Both especially coated to transfer less heat into base metal. Both deposit faster—speed up production, get the job done sooner, do away with a lot of warpage. Both are top-o-the-heap for work on steel.

With these and other advanced All-State Alloys

GOOD WELDERS DO BETTER STEEL

Select right alloy,
Use it right,
Do your best work on

Pocket size folder tells you how Ask your Welding Supply Dist. or write for STEEL FOLDER

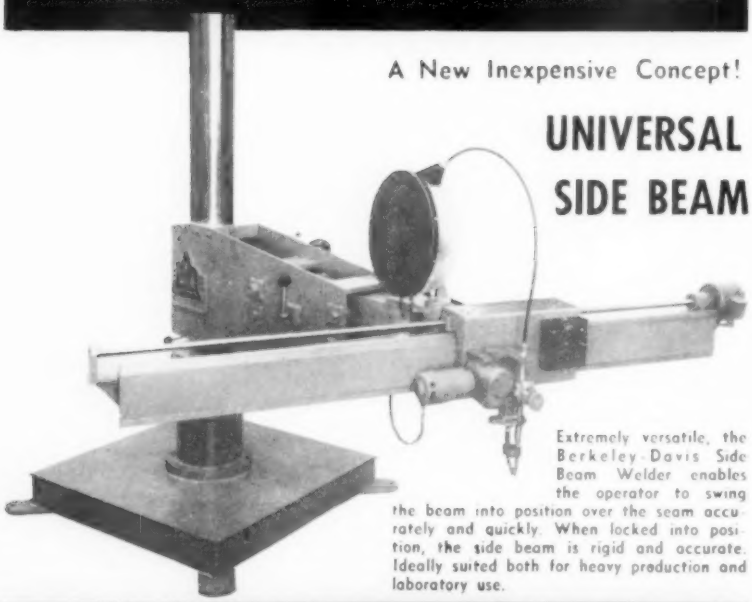
ALL-STATE WELDING ALLOYS CO., INC., WHITE PLAINS, N. Y.

For more details, circle No. 42 on Reader Information Card

SOMETHING NEW FROM B/D

A New Inexpensive Concept!

UNIVERSAL SIDE BEAM



Extremely versatile, the Berkeley-Davis Side Beam Welder enables the operator to swing the beam into position over the seam accurately and quickly. When locked into position, the side beam is rigid and accurate. Ideally suited both for heavy production and laboratory use.

Berkeley-Davis Incorporated AFFILIATED WITH THE Federal MACHINE AND WELDER COMPANY

1021 BAHLS ST. • DANVILLE, ILLINOIS

For more details, circle No. 43 on Reader Information Card

Welding Catalog

All-State Welding Alloys Co., Inc., 249-55 Ferris Ave., White Plains, N. Y., has just published a 6-page catalog designed to specify the applicable alloy and flux for use in various welding problems. The data cover such metals as steel, aluminum and aluminum alloys, cast iron, copper and copper-bearing alloys, magnesium, nickel, monel, stainless steel, silver and zinc die cast.

For your free copy, circle No. 41 on Reader Information Card.

Custom Built Welding Machine

A new 6-page brochure, Form ADG 2076 A, on the function and services of Airco's Machine Welding Department is now available from Air Reduction Sales Co., a Division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y.

The brochure presents descriptive information with illustrations of various types of machine welding installations custom engineered by this department — a service that begins with the design concept and extends to a guarantee of production performance.

The specialized installations range from a machine for welding small transistors to the intricate machines required for the Titan missile.

For your free copy, circle No. 45 on Reader Information Card.

REVIEWS
OF NEW BOOKS

Machine Design

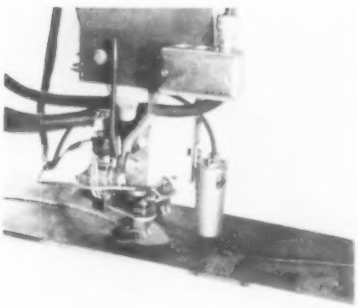
Aids to Efficient Machine Design in Welded Steel, 88 pages, illustrated with pictures, nomographs and tables, 8½ by 11 in., paper-bound cover. Price $1.00. Published by the Lincoln Electric Co., Cleveland 17, Ohio.

This manual contains welded steel design information for machine designers. Techniques, charts, nomographs and data are given for either redesigning from an existing casting or designing from calculated loads. Much of the material is original, while some of it applies standard design techniques and formulas to the problems of steel design. Included in the 12 practical chapters of the manual are methods for redesigning cast bases and cast flywheels; appraisal of steel designs; steel uses for bending loads, torsion resistance and vibratory minimization; design methods for a base and flywheels to load conditions; and designs of bearing supports, fillet welds for strength, welds for bending or twisting and fillet welds for horizontal shear due to bending.

NEW PRODUCTS

Automatic Control

True automatic welding is reportedly achieved with the Lewis "automatic directional control." This automatic seam-following device is a product of The Lewis Welding & Manufacturing Corp., Bedford, Ohio. According to Lewis, the control device, known as LADC, will permit any standard dc automatic welding head to seek out,



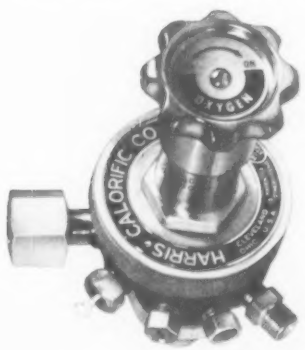
follow and weld accurately straight or nonstraight seams, provided that the head is mounted on Lewis machines. In operation, an error sensing device picks up a signal from the welding voltage. This same signal is amplified and utilized to control the electro mechanical drive mechanism. Since the welding head is mounted on the drive mechanism, a continual, automatic search for the centerline of the weld is effected.

For more details, circle No. 46 on Reader Information Card.

Gaugeless Regulator

Harris Calorific Co., 5501 Cass Avenue, Cleveland, Ohio, has developed a new gaugeless regulator for field-purpose applications.

Known as the Model 77, the gaugeless



field-purpose regulator is designed to reduce maintenance cost otherwise brought about by broken gauges, inlet stems and adjusting screws.

A protruding cylinder content indicator records a full cylinder condition, ¾, ½, ¼, or empty, when flush with the outer container.

Pressure indications are embossed on the bonnet and the adjusting screw is turned in until the thimble attached thereto is placed on the specific pressure required.

For more details, circle No. 47 on Reader Information Card.

Aluminum Safety Cap

A vertically taper-ribbed aluminum safety cap, called "SuperLite," is now being produced by the Fibre-Metal Products Co., 5th & Tilghman Sts., Chester, Pa. Although light in weight, its design is said to enable maximum impact resistance. According to Fibre-Metal, the girder-like construction of

the safety cap is not only rigid but its unique design presents maximum deflection characteristics to blows or falling objects. The cap "shell" is of tough, tempered aluminum. It is cool in that it reflects and does not absorb heat.

For more details, circle No. 48 on Reader Information Card.

a-c Arc Welder

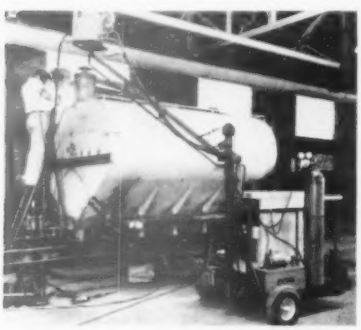
Hobart Bros. Co., Troy, Ohio, has introduced a new a-c transformer-type arc welder, known as the "Hustler," for general job welding, maintenance and repair. Rated at 180 amp, 25 v on 20% duty cycle, operating voltage is 230 v single phase, 60 cycles, with a tap provided for 208-v line voltage when the need arises.

According to Hobart, the "Hustler" can be used for welding, cutting, hole burning, surfacing, soldering, brazing and heating.

For more details, circle No. 49 on Reader Information Card.

Cage Assembly

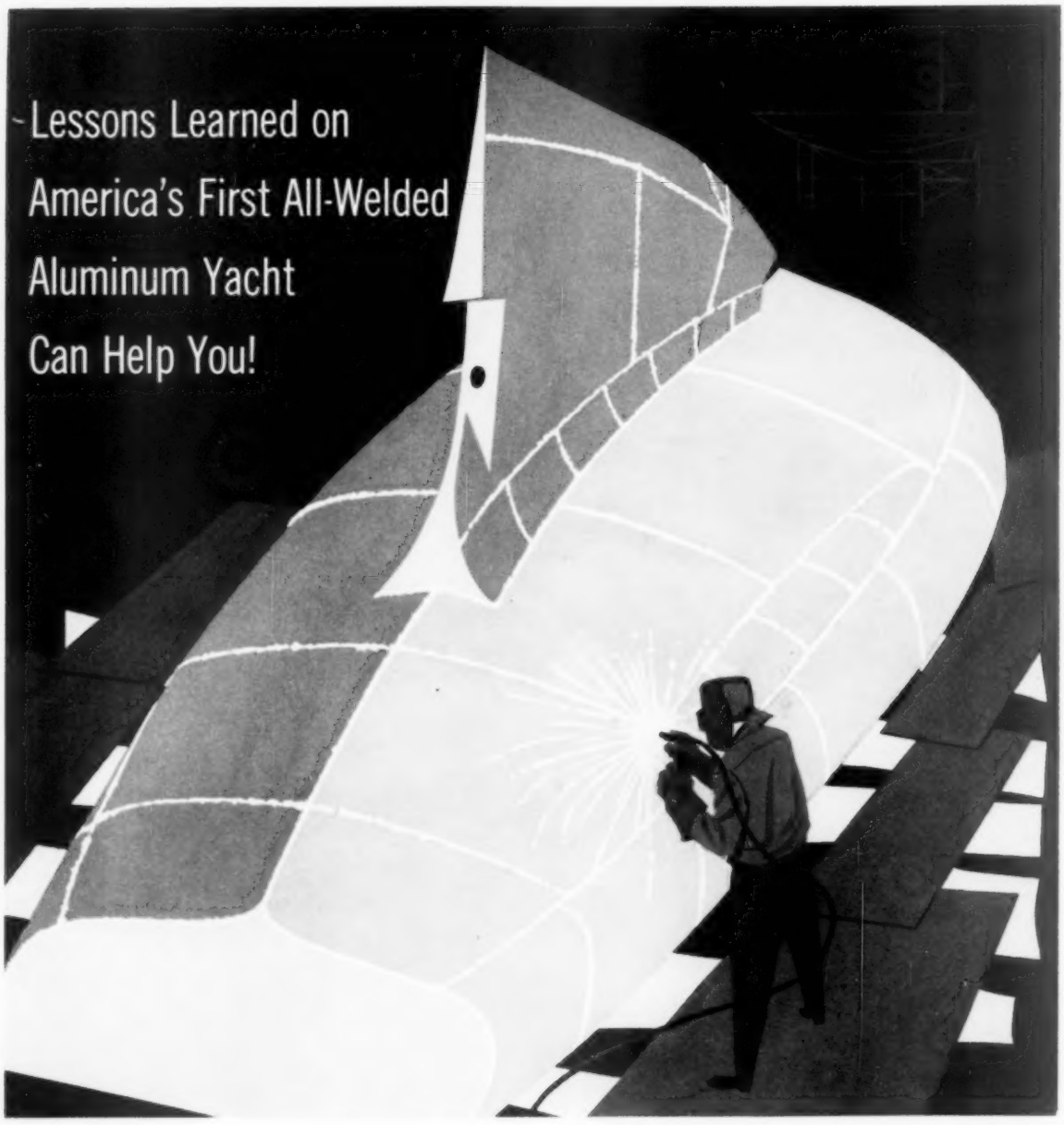
A steel cage assembly to hold and protect semiautomatic welding control and wire-feed units and to provide increased flexibility in welding operations has been introduced by the National Cylinder Gas Division of Chemetron Corp., 840 N. Michigan Ave., Chicago 11, Ill.



Useful to shops fabricating large weldments, the NCG cage assembly can be raised, lowered and moved to any welding position, enlarging work area and providing flexibility within the limits of the type of crane used.

The cage assembly was designed to hold NCG 8A control and wire-feed units and can hold other kinds of equipment. Constructed of ¼-in. steel rod and tubing, it measures 26½ by 16 in. at the base and is 24 in. high. There is a ¾-in. plywood base.

For more details, circle No. 50 on Reader Information Card.



The hull of *Dyna*, America's first all-welded aluminum yacht, will be exposed throughout its life to great stresses, a corrosive environment, and constant battering and vibration. To meet this challenge, Burger Boat Company, of Manitowac, Wisconsin, turned to Alcoa Alloy 5154 and the inert-gas consumable electrode welding process.

Welders at Burger Boat Company had formerly worked exclusively with steel prior to building *Dyna*, yet they had little difficulty in adapting their skills to aluminum. They found that aluminum could be welded at a faster rate than steel, and with relative freedom from warping and distortion. Further, the light weight of the aluminum sections eased handling problems and speeded assembly.

This is another example of the many exciting possibilities in welding, brazing and soldering Alcoa® Aluminum and its alloys. Get in touch with your nearest Alcoa sales office for the kind of design and welding assistance that Alcoa was able to offer Burger Boat Company. For welding materials, contact your local Alcoa distributor listed at the right. For booklets and films that show how easy it is to weld, braze and solder aluminum, write Aluminum Company of America, 1741-G Alcoa Building, Pittsburgh 19, Pennsylvania.

For more details, circle No. 51 on Reader Information Card

ALCOA ALUMINUM

"ALCOA THEATRE"
Exciting Adventure
Alternate Monday Evenings

Your Guide to the Best in Aluminum Value

Want technical help in welding, brazing or soldering aluminum? Contact your Alcoa sales office. Listed under "Aluminum" in the Yellow Pages of your phone book.

For immediate delivery of Alcoa welding products, call your Alcoa outlet listed below. He carries a complete range of alloys and sizes.

ALABAMA
Birmingham
Hinkle Supply Co.

CALIFORNIA
Los Angeles
Ducommun Metals & Supply Co.
Pacific Metals Company, Ltd.
San Francisco
Pacific Metals Company, Ltd.

COLORADO
Denver
Metal Goods Corp.

CONNECTICUT
Milford
Edgcomb Steel of New England, Inc.
Windsor
Whitehead Metal Products Co., Inc.

FLORIDA
Jacksonville
The J. M. Tull Metal & Supply Co., Inc.
Miami
The J. M. Tull Metal & Supply Co., Inc.
Tampa
The J. M. Tull Metal & Supply Co., Inc.

GEORGIA
Atlanta
The J. M. Tull Metal & Supply Co., Inc.
Southern Oxygen Co.

ILLINOIS
Chicago
Machinery & Welder Corp.
Steel Sales Corp.
Moline
Machinery & Welder Corp.

KENTUCKY
Louisville
Williams and Co., Inc.

LOUISIANA
New Orleans
Metal Goods Corp.

MARYLAND
Baltimore
Southern Oxygen Co.
Whitehead Metal Products Co., Inc.
Bladensburg
Southern Oxygen Co.
Salisbury
Southern Oxygen Co.

MASSACHUSETTS
Cambridge
Whitehead Metal Products Co., Inc.

MICHIGAN
Detroit
Steel Sales Corp.

MISSOURI
Kansas City
Metal Goods Corp.
St. Louis
Metal Goods Corp.

NEW HAMPSHIRE
Nashua
Edgcomb Steel of New England, Inc.

NEW JERSEY
Harrison
Whitehead Metal Products Co., Inc.
Merchantville
Southern Oxygen Co.
Vineland
Southern Oxygen Co.

NEW YORK
Buffalo
Whitehead Metal Products Co., Inc.
New York
Southern Oxygen Co.
Whitehead Metal Products Co., Inc.
Syracuse
Brace-Mueller Huntley, Inc.
Whitehead Metal Products Co., Inc.

NORTH CAROLINA
Asheville
Southern Oxygen Co.
Charlotte
Southern Oxygen Co.
Greensboro
Southern Oxygen Co.
Raleigh
Southern Oxygen Co.

OHIO
Cincinnati
Williams and Co., Inc.
Cleveland
Nottingham Steel & Aluminum Co.
Williams and Co., Inc.
Columbus
Williams and Co., Inc.
Toledo
Williams and Co., Inc.

OKLAHOMA
Tulsa
Metal Goods Corp.

OREGON
Portland
Pacific Metal Co.
J. E. Haseltine & Co.

PENNSYLVANIA
Philadelphia
Edgcomb Steel Co.
Southern Oxygen Co.
Whitehead Metal Products Co., Inc.
Pittsburgh
Williams and Co., Inc.
York
Southern Oxygen Co.

TENNESSEE
Kingsport
Southern Oxygen Co.
Knoxville
Southern Oxygen Co.

TEXAS
Beaumont
Big Three Welding Equip. Co.
Corpus Christi
Big Three Welding Equip. Co.
Dallas
Metal Goods Corp.
Texas Welding Supply Co.
Houston
Metal Goods Corp.
Big Three Welding Equip. Co.
San Antonio
Big Three Welding Equip. Co.

UTAH
Salt Lake City
Pacific Metals Company, Ltd.

VIRGINIA
Arlington
Southern Oxygen Co.
Charlottesville
Southern Oxygen Co.
Lynchburg
Southern Oxygen Co.
Norfolk
Southern Oxygen Co.
Richmond
Southern Oxygen Co.
Roanoke
Southern Oxygen Co.

WASHINGTON
Seattle
Pacific Metal Co.
J. E. Haseltine & Co.
Spokane
J. E. Haseltine & Co.

WEST VIRGINIA
Bluefield
Southern Oxygen Co.

WISCONSIN
Milwaukee
Machinery & Welder Corp.
Steel Sales Corp.

Circle No. 51 on Reader Information Card

Cutting Tips

Three new, two-piece cutting tips for use with LP gases are announced by Victor Equipment Co., 844 Folsom St., San Francisco 7, Calif.

These tips, called the LPC-G series, are designed to get maximum cutting efficiency from the use of petroleum, natural and city gases. One type is for general hand cutting; a second for fast preheating and general cutting; and the third for speed tip machine cutting. Sizes range from 00 through 8.

For more details, circle No. 52 on Reader Information Card.

A-c, D-c Electrode

EutecTrode 6800, an alloyed electrode designed to impart machinable deposits of toughness, strength and resistance to heat and corrosion, has been announced by Eutectic Welding Alloys Corp., 40-40 172nd St., Flushing 58, N.Y.

The features of this new electrode for steels and nickel-base alloys, include hot toughness, corrosion resistance and deposit machinability.

Providing an as-deposited hardness to 210 BHN, EutecTrode 6800 is recommended for mild, low alloyed and stainless steels, and for joining those metals to nickel-base alloys such as the Hastelloys, Inconel and the Illiums.

For more details, circle No. 53 Reader Information Card.

Aluminum Deoxidizer

Deoxalum, a new aluminum cleaner and deoxidizer, is now available from Clarkson Laboratories, Inc., 930 N. Darien St., Philadelphia 23, Pa. The new liquid is applied by brushing on the aluminum surfaces before welding or joining. It is said to clean and deoxidize the surface in one operation.

It removes organic contaminators and surface oxides, and the resulting metal surface is clean and low in electrical resistance.

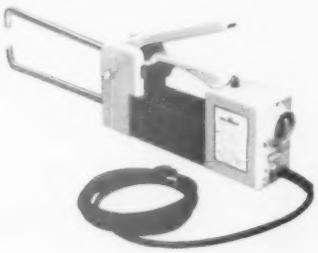
The manufacturer points out that surfaces treated with Deoxalum can be successfully welded after cleaning with a minimum change in uniformity and resistance.

Deoxalum is used without dilution, eliminating the use of strong caustics and replacing strong acids. It is a cold deoxidizer.

For more details, circle No. 54 on Reader Information Card.

Portable Spot Welder

Miller Electric Manufacturing Co., Inc., Appleton, Wis., announces a new spot welder named the "Leetro Spot" with a built-in electronic timer, claimed to produce uniform welds. Both timer and handle pressure multiplier are said



to be instantly adjustable. When the operating handle is depressed, tongs grip the work at predetermined pressures, the start switch is actuated and the weld sequence starts and stops automatically. Available in three models: 110 v or 220 v 1.5 kva models weighing 29 lb, and 220 v 2.5 kva size at 39 lb.

For more details, circle No. 55 on Reader Information Card.

Large Fillet Brazing

A new Nicrobraz brazing alloy for high-temperature service, especially developed for use with large clearances up to 0.050 in., is now available from the Stainless Processing Division of Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich.

Designated W. G. Nicrobraz brazing alloy, the new material is recommended for use in nonrotating lightly loaded parts and structural assemblies, that

have cross-sectional thicknesses of $\frac{1}{16}$ in. or greater. It is reported to be well suited for applications where large fillets are desired.

For more details, circle No. 56 on Reader Information Card.

Turning Rolls

The Pandjiris Weldment Co., 5151 Northrup Ave., St. Louis 10, Mo., has introduced a new design (patent pending) in power turning roll equipment.

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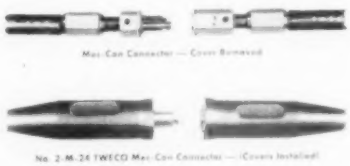

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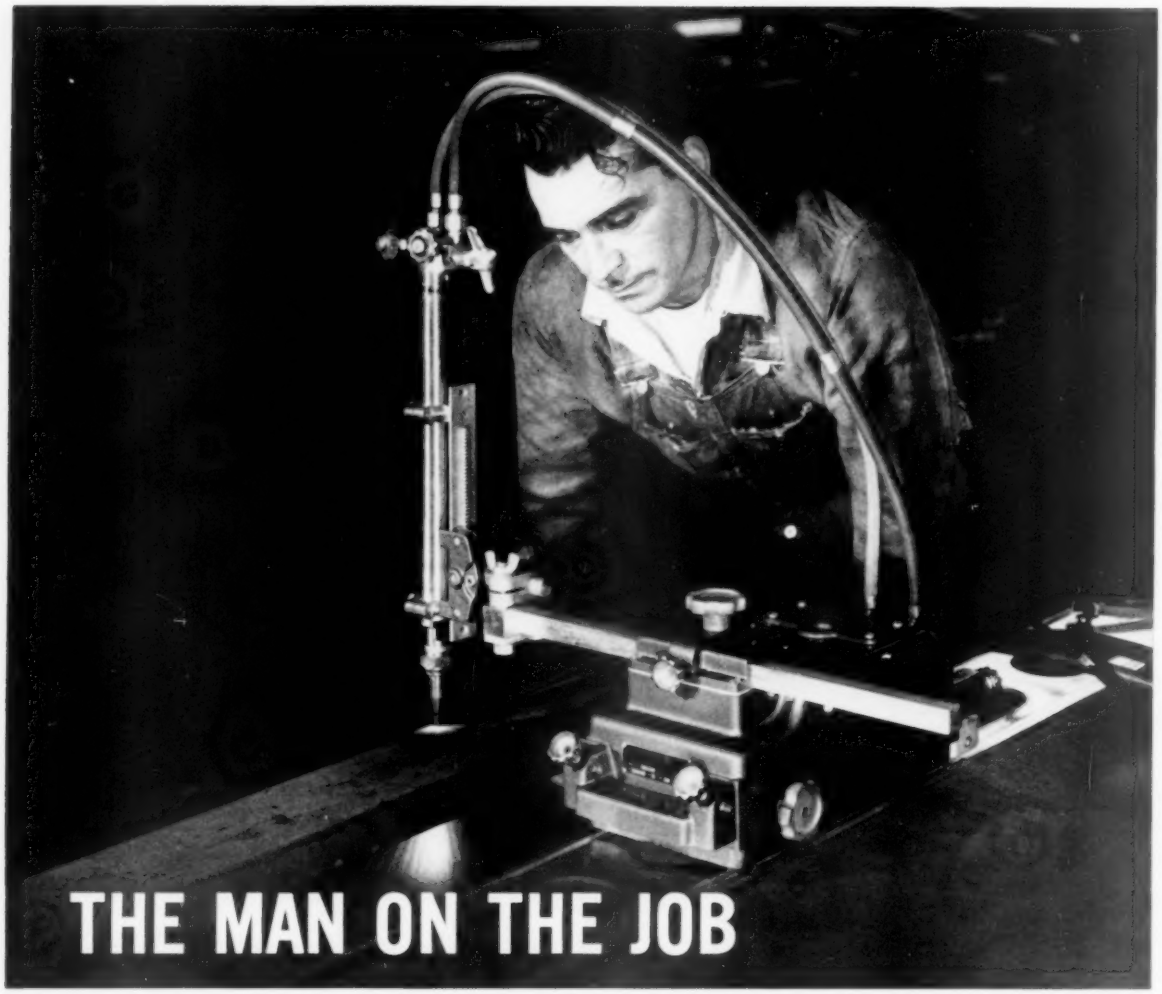

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PREDICTION OF WELD HEAT-AFFECTED ZONE MICROSTRUCTURES FROM CONTINUOUS-COOLING TRANSFORMATION DATA

Investigation indicates that microstructures of the heat-affected zones of welds can be predicted from continuous-cooling transformation data with a fair degree of accuracy

BY E. F. NIPPES AND E. C. NELSON

ABSTRACT. A system of predicting the microstructures of the heat-affected zones of welds from continuous-cooling transformation data and weld-thermal cycles is described. Microstructures of experimental welds are compared with the predicted microstructures, and the system of calculations and its experimental foundations are analyzed to explain the differences between theory and actual welds.

Introduction

The reduction of weldability to a series of computation operations will depend on a complete understanding of the complex interrelationships between the individual mechanical properties of the various microstructurally distinct regions of the base plate, heat-affected zone and the weld metal. In addition, the effects of stresses arising from thermal expansions and contractions, and volume changes during transformation must be considered.

A beginning towards the solution of this formidable problem has been made by the development of a generalized system for determining the cooling rates associated with arc welds for a variety of welding conditions for steel plate.[1]

E. F. Nippes and E. C. Nelson are associated with the Department of Metallurgical Engineering, Rensselaer Polytechnic Institute, Troy, New York.

An extension of this work[2] describes a method of calculating the complete time-temperature cycle at any position in the heat-affected zone of an arc weld on ½-in. thick steel plates. Recent unpublished data[3] have extended this generalized system to include the case of arc welds in 1-in. thick steel plates. These latter data are given in the Appendix.

These cooling-rate calculations have been incorporated into a weldability design system which requires that hardness or metallographic tests be made on a Jominy bar of the steel under consideration. Data from the Jominy test are translated into the cooling rate required to cause transformation of the steel to a specific hardness or into a specific microstructure.

Extension of this calculated weldability concept to predict microstructures without the use of the Jominy bar or other laboratory tests is possible if complete information is available on the continuous-cooling transformation behavior of a particular steel. Data of this sort are not commonly found in the metallurgical literature because of the difficulty of the experimental work required. The development of a high-speed dilatometer capable of operating over a wide temperature range[4] has resulted in the determination of continuous-cooling transformation diagrams of a limited number of steel compositions. These diagrams are sufficiently complete to provide a test of the system of calculated weld heat-affected-zone microstructures.

Materials

Continuous-cooling transformation diagrams covering a range of temperatures from the beginning of austenitization up to 2450° F were available for two high-alloy steels. One of these steels was boron treated and was chosen because its hardenability showed an abrupt decrease at temperatures above 2100° F. The composition of this steel was as follows: % C 0.27, % Mn 1.20, % Si 0.19, % Ni 0.82, % Cr 0.79, and % Mo 0.19. This apparent loss of the contribution of boron to hardenability after austenitizing at elevated temperatures is commonly recognized but has not yet been completely explained.[5] The first high-speed dilatometer specimen which showed this behavior was re-austenitized at a lower temperature as a check on possible de-

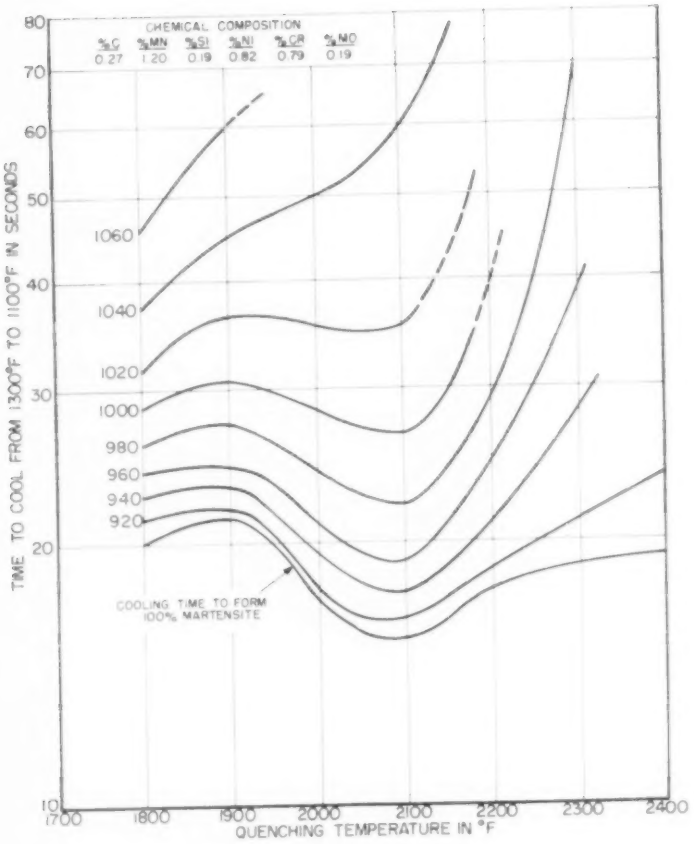

Fig. 1 Isotherms for beginning of transformation for a boron-treated steel

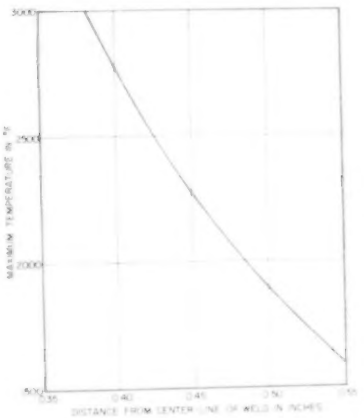

Fig. 2 Maximum temperature as a function of distance from the center line of a weld in 1-in. thick steel plate with 100,000 joules/in. energy input and a preheat of 400° F

carburization. The behavior of this specimen was consistent with the transformation diagram of the steel at the lower austenitizing temperature.

A continuous-cooling transformation diagram for the boron-treated steel is shown in Fig. 1. This is a "transformation isotherm diagram" whose derivation from time-temperature-transformation diagrams for continuous cooling has been previously described.[5] Briefly, continuous-cooling transformation curves obtained for a number of austenitizing temperatures are replotted to show transformation temperatures as a function of the time to cool from 1300 to 1100° F. A line is drawn through points showing the beginning of transformation at a given temperature (in ° F) as a function of both the time to cool from 1300 to 1100° F and the austenitizing temperature. Such a diagram conveniently summarizes the transformations on continuous cooling at various quenching rates as a function of austenitizing temperatures.

The lowest curve on Fig. 1 does not bear a transformation-temperature designation. This curve represents the maximum cooling time which produces an entirely martensitic structure. Because the austenitizing times used in preparing this transformation diagram were brief, to approximate the austenitizing conditions in a weld heat-affected zone,[5] the temperatures of transformation along this curve decrease with increasing austenitizing temperatures as carbide solution becomes more complete.

The shape of the time-to-cool curve for 100% martensite formation is not a simple function of the austenitizing temperature. From 1800 to 1900° F the hardenability increases as carbide and alloy solution become more complete. At higher temperatures the hardenability decreases drastically because of the loss of effectiveness of boron at high austenitizing temperatures. Above 2100° F rapid grain growth, coupled with practically complete solution of alloys and carbon, causes an increase in the hardenability. The minimum in hardenability at austenitizing temperatures near 2100° F indicates that there must exist a set of welding conditions which would produce a heat-affected zone consisting entirely of martensite except for a thin band of nonmartensitic decomposition products located at an appreciable distance from both the fusion line and the edge of the heat-affected zone. The prediction and formation of this structure provide a critical and unequivocal test of the system of calculated weldability.

Calculations

Previous work[1] has demonstrated that the difference between the instantaneous temperature at any point in the heat-affected zone of a weld and the initial temperature of the plate is a complex function of the energy input, the distance from the centerline of travel of the arc, and the time. This temperature difference can be expressed[2] as a single function of the distance

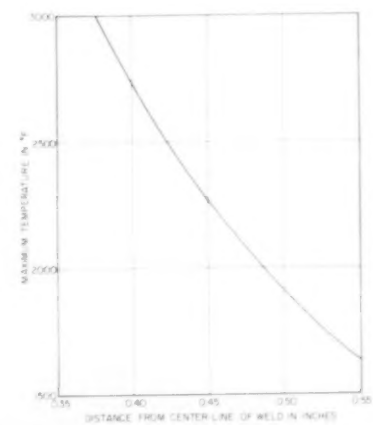

Fig. 3 Maximum temperature as a function of distance from the centerline of a weld in 1-in. thick steel plate with 100,000 joules/in. energy input and a preheat of 500° F

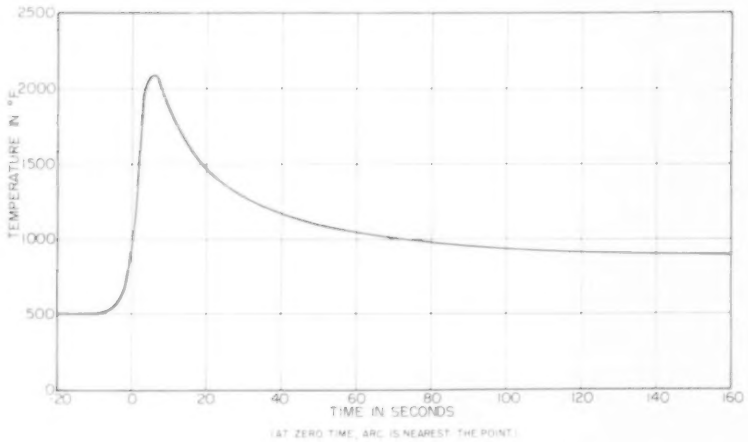

Fig. 4 Calculated time-temperature curve for a point 0.47 in. from the centerline of a weld in 1-in. thick steel plate with 100,000 joules/in. energy input and a preheat of 500° F

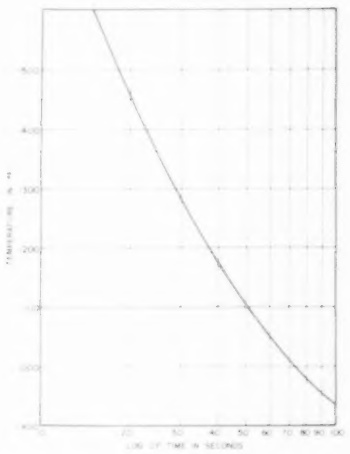

Fig. 5 The data of Fig. 4 replotted on a semilogarithmic scale for greater precision in the determination of the time to cool from 1300 to 1100° F

"d", and the time "s" multiplied by the energy input in kilojoules per inch. Thus

$$T - T_0 = F(s, d)\ \text{(kilojoules per inch)}$$

where

T = instantaneous temperature,

T_0 = original temperature of the plate.

The values of $F(s,d)$ are independent of welding conditions over a wide range of energy input. In the case of preheated inputs the function must be multiplied by a preheat factor.[2]

The values of $F(s, d)$ for 1-in. plates are given in the Appendix as variable functions of time and distance. Thus, for a given energy input, the thermal history of any given point in the heat-affected zone of an arc weld can be determined by multiplying the energy input by the tabular values of $F(s, d)$ for that position, as these values vary with time.

The points in the experimental welds which supplied the data from which the $F(s, d)$ tables were calculated, lay in a plane parallel to the top surface of the plate and at a depth of 0.050 in. below the top surface. This depth was chosen because of its ease of duplication and the fact that loss of heat by radiation from the surface does not affect the temperatures recorded at this depth.

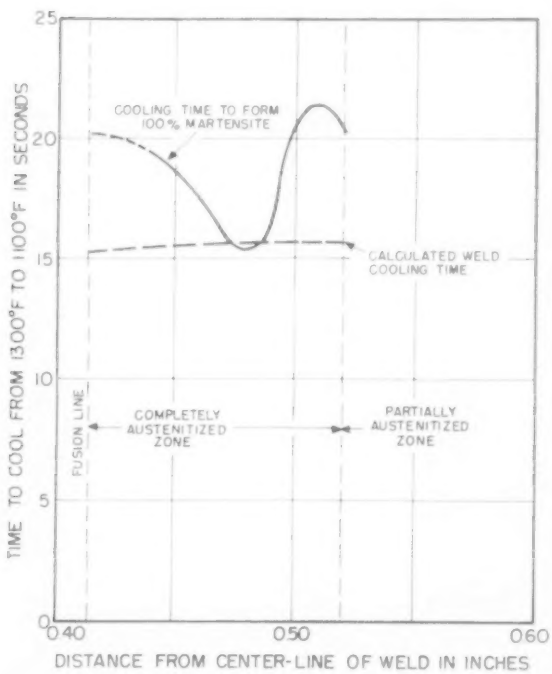

Fig. 6 Comparison of base-metal critical cooling times with calculated weld cooling times within the completely austenitized region of the heat-affected zone of a weld in a 1-in. thick boron-treated steel plate made with 100,000 joules/in. and a preheat of 400° F

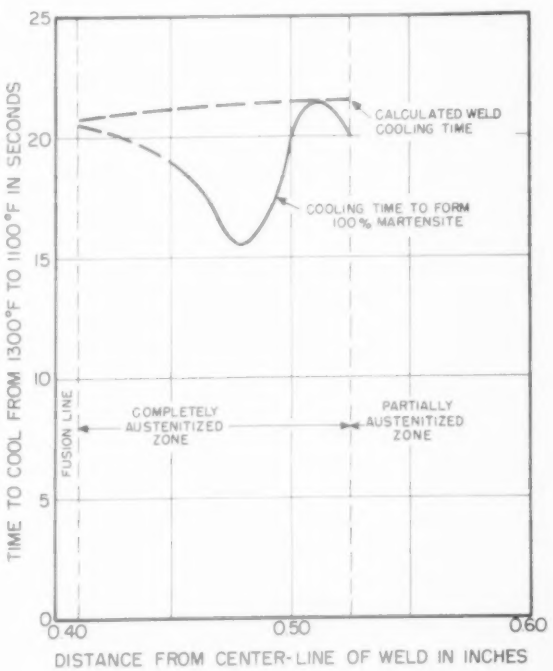

Fig. 7 Comparison of base-metal critical cooling times with calculated weld cooling times within the completely austenitized region of the heat-affected zone of a weld in a 1-in. thick boron-treated steel plate made with 100,000 joules/in. and a preheat of 500° F

Fig. 8 Coarse grains of martensite at the fusion line of the weld made with 500° F preheat. X 500. 0.5% Nital etch

Fig. 9 Coarse grains of martensite at the fusion line of the weld made with 400° F preheat. X 500. 0.5% Nital etch

Fig. 10 Nonmartensitic structure within the heat-affected zone of the weld made with 500° F preheat. X 500. 0.5% Nital etch

Thus, the specific "distance from the centerline of the weld" strictly applies only to points in a plane parallel to the top surface of a plate and at a depth of 0.050 in. below the surface. However, such points within the heat-affected zone lie on isotherms whose contours follow the shape of the fusion line. Hence, cooling conditions in the heat-affected zone which are originally located in terms of distance from the centerline of the weld can be re-located in terms of distance from the fusion line, along isotherms which are symmetrical with the fusion line.

In performing these calculations, it is desirable first to limit the number of distance values which must be considered by establishing the maximum temperatures reached at various positions in the heat-affected zone. This is done by making use of the maximum *F(s, d)* values listed in the Appendix for each position in the heat-affected zone. Maximum temperature curves as a function of distance are shown in Fig. 2 for an energy input of 100,000 joules per inch and a preheat temperature of 400° F, and in Fig. 3 for the same energy input with a preheat temperature of 500° F. The distance values for which detailed calculations must be made are those lying between the melting point of the steel and the minimum temperature of complete austenitization on the curves of Figs. 2 and 3. The minimum temperature for complete austenitization under rapid heating conditions had been found experimentally to be 1800° F. The melting point was taken as 2700° F.

The use of the time to cool from 1300 to 1100° F as a measure of quenching speed in presenting the transformation data of Fig. 1 is discussed in Ref. 6. Briefly, this criterion was chosen to permit information obtained from high-speed-dilatometer specimens to be used in calculating the microstructures in a weld, where the shape of the time-temperature curve cannot be expected to correspond exactly to that of the high-speed-dilatometer specimen.

The remainder of the calculations consists of determining the time to cool from 1300 to 1100° F across the heat-affected zone within the distance limits found from Figs. 2 and 3.

The total time-temperature curve at each position can be calculated readily from the tables of *F(s, d)*. A plot of such a curve is shown in Fig. 4. When the data of Fig. 4 are replotted as temperature vs. log time, Fig. 5, the function becomes almost a straight line, and the time to cool from 1300 to 1100° F can be measured with greater ease and accuracy.

The results of a series of such calculations for points at 0.01-in. intervals across the completely austenitized region of the heat-affected zone can be plotted as a curve showing the variation in the time to cool from 1300 to 1100° F across the zone. When such a curve is combined with information from a transformation diagram (Fig. 1), with maximum temperatures on the latter diagram transposed into distances by means of the calculated maximum temperature vs. distance curve (Fig. 2), the resulting data can be used to predict the microstructure of the heat-affected zone.

Figure 6 shows the data for cooling time to form 100% martensite from Fig. 1 combined with the weld cooling time for 400° F preheat and 100,000 joules per inch energy input. Figure 7 shows the same calculations for the case of a 500° F preheat.

According to Fig. 6, a weld made with an energy input of 100,000 joules per inch and a 400° F preheat should have a heat-affected zone consisting almost entirely of martensite. Figure 7, on the other hand, indicates that with the same energy input, but with a preheat of 500° F, the heat-affected zone should contain varying amounts of nonmartensitic decomposition products.

Experimental Procedure

Test welds were made with the same measuring and automatic welding equipment which had been used to obtain the data of References 1, 2, and 3. The welding conditions were monitored using automatic current, voltage and power recording instruments. Type 260 electrodes, $\frac{5}{32}$ in. in diameter, were used in making the test welds. The electrodes were dried at 600° F in a circulating-air furnace for four hours immediately before welding. The analysis of the deposited weld metal was as follows: % C 0.07, % Mn 1.00, % Si 0.40, % Ni 1.80, % Mo 0.82, and % V 0.27.

The welds were made on 18- x 9- x 1-in. plates. The high-speed-dilatometer specimens used to obtain the data of Fig. 1 had been machined from the same size of plates from the same heat of steel. The length and width of the plate were sufficiently large to ensure the absence of edge effects in the neighborhood of the welds.

The preheat temperature was established by a technique which had been found to be satisfactory during the course of the investigation reported in Reference 1. The plate was heated manually with an oxyacetylene torch to a temperature 100° F above the desired preheat temperature. Temperatures were measured with a contact pyrometer and care was taken to heat uniformly. The plate-supporting members of the welding apparatus were also carefully heated to avoid chilling from this source. The surface temperature of the plate was measured periodically at various points as the plate cooled. When the surface temperature reached the desired preheat temperature, the arc was struck and the test weld made.

After welding, the weldments were allowed to cool in air to room temperature and then were sectioned through their midpoints normal to the direction of welding, for microscopic examination.

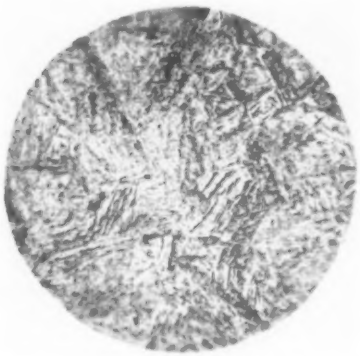

Fig. 11 Region of the heat-affected zone of the weld made with 400° F preheat which corresponds in relative location to the region of Fig. 10. The structure is entirely martensitic. X 500. 0.5% Nital etch

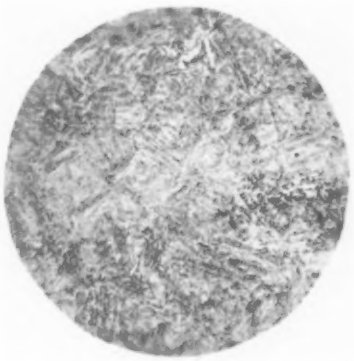

Fig. 12 Structure of the heat-affected zone of the weld made with 500° F preheat at a region farther from the fusion line than that of Fig. 10. The structure is entirely martensitic. X 500. 0.5% Nital etch

Experimental Results

The microstructures found in the heat-affected zones of the test welds were somewhat different than had been predicted. The weld made with a preheat of 400° F had an entirely martensitic heat-affected zone, while the weld made with a preheat of 500° F had a heat-affected zone consisting of a narrow band of nonmartensitic decomposition products, enclosed on either side by martensite.

Figure 8 shows coarse grains of martensite near the fusion line of the 500° F preheat weld, while Fig. 9 shows the same microstructure at the corresponding region of the 400° F preheat weld.

Figure 10 shows patches of ferrite and carbide among grains of martensite within the heat-affected zone of the 500° F preheat weld. This structure is a consequence of the drop in hardenability of the steel at austenitizing temperatures in the neighborhood of 2100° F. Figure 11 shows the entirely martensitic structure of the weld made in the 400° F preheat at a position corresponding in relative location to that of Fig. 10. Figure 12 shows the entirely martensitic structure found in the 500° F preheat weld in the region between the edge of the heat-affected zone and the location of the structure shown in Fig. 10.

Analysis of Results

In view of the complexity of different separate experimental data which were used in predicting the weld microstructures, a fair degree of success can be claimed on the basis of the test welds. The fact that the 400° F preheat weld heat-affected zone was entirely martensitic and the 500° F preheat weld had a microstructure containing more martensite than predicted provides a basis for rationalizing the lack of perfect agreement of theory with practice.

The actual weld microstructures differed from those predicted in a manner which could be accounted for either by faster cooling than was predicted in the weld or by a higher hardenability of the steel than that given by the continuous-cooling transformation diagram.

The data used in the calculations of Figs. 6 and 7 resulted from two separate and complex experimental investigations: the derivation of the weld thermal cycle data[1, 2, 3] and the determination of the continuous-cooling transformation curve.[4] Errors in either investigation could have operated individually or in cumulative effect to produce the observed results. The two sets of data will be considered separately.

If the weld cooling-time data of Figs. 6 and 7 are correct, then the experimental welds indicate that the critical cooling times used are too small; that is, the hardenability of the steel is higher than the continuous-cooling transformation data indicate. The critical-cooling-time curve (cooling time to form 100% martensite) of Fig. 6 should be entirely above the weld cooling curve to account for the completely martensitic heat-affected zone found in the weld made with 400° F preheat. In the same manner, the critical-cooling-time curve of Fig. 7 should be higher and should intersect the weld-cooling-time curve.

Decarburization is one of the greatest experimental difficulties encountered with the high-speed dilatometer, and a source of error which would lower the apparent hardenability. This problem and its solution were discussed in detail in Reference 4. All specimens which contributed data to Fig. 1 were examined metallographically for evidence of decarburization, and data from any suspect specimens were discarded.

Decarburization will increase exponentially with temperature, and any systematic error from this source would cause the transformation diagrams to show a drastic decrease in hardenability with increasing quenching temperatures. However, the critical-cooling-time curve of Fig. 1 shows the hardenability increasing at temperatures above 2100° F, where decarburization difficulties are most severe.

The fact that a martensitic structure was found on either side of a partially nonmartensitic region in the heat-affected zone of the weld made with 500° F preheat gives support to the correctness of the transformation data. Only a variation in transformational behavior, as indicated in Fig. 1 for the cooling time to form 100% martensite, could produce such a structure.

The high hardenability of the boron steel required the use of an indirect heating device to produce slow cooling rates.[5] This device slowed the heating rate of the specimens so that 30 to 40 sec were required to reach the quenching temperature. This is appreciably longer than the 6- to 8-sec heating cycle in the arc welds, and thus the dilatometer specimens were more thoroughly austenitized for any given maximum temperature than the corresponding position in the weld heat-affected zone. An error from this source, however, would be in the opposite direction from the observed errors.

If the most probable error in the transformation diagram is in the direction of too high a hardenability, then the test welds indicate that the actual cooling rates were faster than had been predicted.

The basic mathematical relationships in Reference 1 do not contain any physical limits to their application. The variables of plate thickness and preheat temperature are accounted for by appropriate factors, and the data should be capable of extension to conditions of energy input and preheat temperature beyond those for which the values of $F(s, d)$ were obtained. It is possible, however, that the $F(s, d)$ data or the preheat factors might be unreliable at the extremely high energy input and preheat temperatures required by the highly hardenable steel used in this investigation.

Experimental evidence, showing that the cooling rates actually were faster than those calculated, was obtained by measuring the widths of the completely austenitized regions of the heat-affected zones. Figures 2 and 3 show that these widths should be 0.11 in.; whereas they were only about 0.08 in. in the experimental welds.

Conclusions

The microstructures of the heat-affected zones of welds can be predicted from continuous-cooling transformation

data with a fair degree of accuracy. The lack of perfect agreement between calculated and experimental weld microstructures can be explained best by the unreliability of weld thermal cycle data at extremely high energy inputs and preheat temperatures.

Acknowledgment

The authors wish to express their gratitude to the late W. F. Hess for his interest and encouragement. This work was supported by the Ordnance Department, U. S. Army through the Watertown Arsenal, under Contract DA-30-115-ORD-250.

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APPENDIX

Table 1—Values of $F(s, d)$ in Equation: $T - T_0 =$ (Kilojoules/in.) $F(s, d)$

For the Last Pass in Single-Vee Butt Welds in 1-in. Plates

(Temperature in ° F, distance in inches, plates initially at room temperature, 5/32-in. electrodes)

Time in Sec.	d = 0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35	0.36
−2	3.71	3.64	3.58	3.52	3.46	3.40	3.34	3.28	3.22	3.16	3.10	3.04
−1	6.76	6.63	6.50	6.37	6.25	6.12	5.99	5.87	5.75	5.62	5.50	5.38
0	9.49	9.30	9.11	8.92	8.74	8.55	8.37	8.18	8.00	7.81	7.63	7.36
1	17.85	17.45	17.05	16.65	16.25	15.85	15.46	15.07	14.68	14.29	13.91	13.53
2	26.8	26.2	25.5	24.8	24.15	23.45	22.75	22.05	21.35	20.65	19.95	19.3
3	38.4	37.3	36.3	35.15	34.0	32.9	31.75	30.7	29.7	28.7	27.65	26.7
4	46.55	45.25	43.95	42.6	41.25	39.8	38.4	37.0	35.6	34.3	32.9	31.45
5	48.7	47.3	45.85	44.4	42.95	41.55	40.15	38.8	37.35	35.9	34.6	33.2
6	48.3	45.95	43.9	42.65	41.45	40.15	38.9	37.65	36.4	35.1	33.85	32.6
7.5	40.3	39.3	38.3	37.3	36.3	35.25	34.2	33.15	32.1	31.05	30.0	29.1
10	30.9	30.25	29.6	28.95	28.25	27.6	26.95	26.3	25.65	24.95	24.3	23.7
15	20.4	20.2	20.0	19.75	19.5	19.2	18.9	18.6	18.3	17.95	17.6	17.3
20	16.3	16.15	15.98	15.8	15.6	15.4	15.2	15.0	14.8	14.6	14.4	14.2
30	12.1	12.02	11.98	11.88	11.8	11.7	11.6	11.5	11.4	11.25	11.19	11.03
40	9.85	9.80	9.75	9.70	9.65	9.60	9.52	9.48	9.40	9.34	9.28	9.20
60	7.40	7.39	7.38	7.36	7.33	7.31	7.30	7.29	7.26	7.26	7.23	7.20
80	6.35	6.34	6.32	6.31	6.29	6.28	6.26	6.24	6.23	6.21	6.19	6.17
100	5.65	5.64	5.63	5.62	5.61	5.60	5.59	5.58	5.57	5.56	5.55	5.54
120	5.33	5.34	5.33	5.32	5.31	5.30	5.29	5.28	5.27	5.26	5.25	5.24
150	5.18	5.17	5.16	5.15	5.14	5.13	5.12	5.11	5.10	5.09	5.08	5.07
180	4.96	4.96	4.95	4.94	4.94	4.93	4.92	4.92	4.91	4.902	4.90	4.89
	MAX., 48.8 at 4.86		MAX., 47.3 at 4.88		MAX., 45.8 at 4.903		MAX., 44.4 at 4.93		MAX., 42.95 at 4.96		MAX., 41.55 at 4.99	
	MAX., 40.15 at 5.02		MAX., 38.8 at 5.05		MAX., 37.35 at 5.09		MAX., 36.03 at 5.13		MAX., 34.62 at 5.18		MAX., 33.3 at 5.23	

Time in Sec.	d = 0.37	0.38	0.39	0.40	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.48
−2	2.98	2.92	2.86	2.81	2.75	2.70	2.64	2.59	2.53	2.48	2.42	2.37
−1	5.26	5.14	5.02	4.91	4.79	4.67	4.55	4.44	4.33	4.22	4.11	4.00
0	7.29	7.12	6.95	6.78	6.62	6.46	6.30	6.14	5.98	5.82	5.66	5.51
1	13.15	12.77	12.40	12.02	11.65	11.30	10.94	10.58	10.24	9.88	9.54	9.20
2	18.65	18.0	17.4	16.75	16.1	15.5	14.95	14.35	13.8	13.25	12.72	12.2
3	23.7	24.75	23.8	22.9	22.05	21.25	20.55	19.8	18.9	18.05	17.35	16.8
4	30.4	29.8	27.6	26.2	25.0	23.85	22.75	21.7	20.73	19.83	18.95	18.1
5	31.7	30.8	29.0	27.65	26.4	25.15	24.0	22.9	21.9	20.9	19.95	19.1
6	31.35	30.15	28.95	27.75	26.5	25.3	24.2	23.0	21.95	20.93	19.98	19.1
7.5	28.02	27.1	26.15	25.2	24.3	23.4	22.5	21.7	20.85	20.1	19.33	18.63
10	23.04	22.45	21.8	21.2	20.6	20.03	19.45	18.9	18.33	17.75	17.22	16.73
15	16.93	16.63	16.38	16.0	15.7	15.4	15.1	14.8	14.5	14.25	13.98	13.65
20	14.0	13.78	13.55	13.35	13.1	12.9	12.7	12.5	12.3	12.1	11.9	11.72
30	10.9	10.78	10.63	10.52	10.4	10.3	10.16	10.02	9.95	9.82	9.70	9.60
40	9.12	9.05	8.99	8.90	8.82	8.76	8.69	8.61	8.54	8.47	8.40	8.33
60	7.18	7.15	7.12	7.10	7.07	7.04	7.01	6.98	6.95	6.92	6.89	6.86
80	6.16	6.14	6.12	6.10	6.08	6.06	6.04	6.02	6.00	5.98	5.96	5.94
100	5.53	5.52	5.51	5.50	5.49	5.48	5.47	5.46	5.45	5.44	5.43	5.42
120	5.23	5.22	5.21	5.20	5.19	5.18	5.17	5.16	5.15	5.14	5.13	5.12
150	5.065	5.06	5.05	5.04	5.03	5.02	5.01	5.00	4.99	4.98	4.97	4.965
180	4.88	4.87	4.87	4.86	4.85	4.84	4.84	4.83	4.82	4.81	4.80	4.80
	MAX., 31.8 at 5.28		MAX., 30.8 at 5.33		MAX., 29.8 at 5.38		MAX., 28.9 at 5.43		MAX., 28.0 at 5.49		MAX., 27.1 at 5.54	
	MAX., 26.2 at 5.59		MAX., 25.4 at 5.64		MAX., 24.62 at 5.70		MAX., 23.9 at 5.75		MAX., 23.19 at 5.80		MAX., 22.5 at 5.86	
	MAX., 21.85 at 5.91		MAX., 21.2 at 5.97		MAX., 20.57 at 6.02		MAX., 19.95 at 6.08		MAX., 19.35 at 6.13		MAX., 18.75 at 6.19	

Time in Sec.	d = 0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.60	0.70	0.80	0.90	1.00	1.20
−2	2.31	2.26	2.20	2.15	2.10	2.05	2.00	1.75	1.3	0.85	0.4	0	0
−1	3.89	3.78	3.67	3.57	3.47	3.37	3.27	2.81	1.95	1.25	0.65	0.2	0
0	5.36	5.22	5.06	4.92	4.76	4.64	4.50	3.82	2.6	1.58	0.8	0.33	0
1	8.87	8.54	8.22	7.90	7.59	7.28	6.98	5.6	3.4	1.95	1.05	0.47	0
2	11.7	11.25	10.8	10.35	9.95	9.50	9.10	7.10	4.00	2.20	1.20	0.60	0
3	15.9	15.2	14.5	13.85	13.15	12.5	11.85	8.70	5.30	3.35	2.15	1.40	0.65
4	17.3	16.5	15.75	15.05	14.35	13.6	12.92	9.70	6.30	4.25	2.90	2.50	1.25
5	17.95	17.2	16.4	15.7	15.0	14.25	13.55	10.3	7.10	5.00	3.50	2.70	1.75
6	18.28	17.5	16.73	15.95	15.3	14.6	13.95	10.8	7.70	5.65	4.20	3.20	2.18
7.5	18.9	17.9	16.9	15.95	15.3	14.7	14.1	11.3	8.30	6.35	4.80	3.80	2.65
10	16.15	15.65	15.2	14.7	14.25	13.82	13.4	11.4	8.80	7.00	5.50	4.50	3.25
15	13.4	13.15	12.85	12.6	12.38	12.1	11.85	10.6	8.70	7.25	6.15	5.30	4.00
20	11.52	11.35	11.12	10.98	10.8	10.6	10.42	9.60	8.20	7.20	6.30	5.70	5.00
30	9.50	9.40	9.30	9.20	9.08	8.98	8.88	8.40	7.50	6.80	6.20	5.80	5.15
40	8.27	8.20	8.12	8.05	8.00	7.93	7.87	7.60	7.00	6.45	6.00	5.60	5.00
60	6.83	6.80	6.77	6.74	6.71	6.68	6.65	6.50	6.15	5.80	5.50	5.25	4.80
80	5.92	5.90	5.88	5.87	5.85	5.83	5.81	5.72	5.55	5.35	5.15	4.95	4.60
100	5.41	5.40	5.39	5.38	5.37	5.36	5.35	5.30	5.15	5.00	4.85	4.75	4.50
120	5.11	5.10	5.09	5.08	5.07	5.06	5.05	5.00	4.90	4.80	4.70	4.60	4.36
150	4.90	4.90	4.89	4.88	4.87	4.86	4.85	4.80	4.75	4.65	4.55	4.46	4.36
180	4.79	4.78	4.77	4.76	4.76	4.75	4.74	4.70	4.61	4.52	4.43	4.35	4.27
	MAX., 18.3 at 6.40		MAX., 17.6 at 6.42		MAX., 16.8 at 6.45		MAX., 16.10 at 6.80		MAX., 15.4 at 6.50		MAX., 14.72 at 6.55		
	MAX., 14.1 at 7.45		MAX., 13.5 at 9.20										

Table 2—Multipliers to Convert Tabular Values of $F(s, d)$ to Corresponding Values at Preheat Temperatures up to 500° F

Plate temperature T_0, ° F	*Multiplier*
32	1.02
72	1.00
210	0.95
400	0.85
500	0.80

WELDING METALLURGY OF Cr-Mo-V STEELS FOR HIGH-TEMPERATURE STEAM-TURBINE COMPONENTS

Procedures developed for welding Cr-Mo-V base metal with a ½% Cr–1% Mo electrode using both the manual metal-arc and submerged-arc processes are discussed by the authors

BY R. J. CHRISTOFFEL, R. M. CURRAN, F. H. DOMINA AND C. H. SOLDAN

ABSTRACT. This report summarizes the procedures, including preheat and post-weld heat treatments, which were developed for welding Cr-Mo-V base metal with a ½% Cr–1% Mo electrode using both the manual metal-arc and submerged-arc processes. The rupture strength of the ½% Cr–1% Mo weld metal, as well as that of other low-alloy-steel weld metals, was evaluated and found to be less than that of the base metal. The effect of composition and heat treatment on the rupture strength of low-alloy-steel weld metals was evaluated. A Cr-Mo-V electrode was developed and qualified for welding the Cr-Mo-V base metal which, in the normalized and tempered condition, had a rupture strength comparable to that of the base metal.

Introduction

As the operating temperature of steam turbines increased to the 950° F level in the past several decades, materials utilized progressed from carbon steel through the straight ½% and 1¼% molybdenum grades to the chromium-molybdenum steels. Although a number of first units built to operate at the 1050° F level utilized the austenitic stainless steels for turbine piping, valve and shell components, the vanadium-containing Cr-Mo steels have been utilized almost exclusively in more recent years for high-temperature components of machines operating at this temperature level.

The authors' company first started using the molybdenum-vanadium steel in 1948 and has made extensive use of the chromium-molybdenum-vanadium steels for steam turbine applications since 1950. During this period, a number of investigations has been conducted concerning the development of welding procedures and the development of electrodes for welding this steel. The increased interest in the Cr-Mo-V steels for high-temperature pressure-vessel applications, their inclusion in ASTM specifications, and the lack of published data concerning their welding properties, has prompted the decision to present the more important results of these programs in this paper.

Standard welding-procedure qualification tests describe the room-temperature tensile and bending properties of the welded joints in low-alloy steels but no requirements have been established for high-temperature strength. This property is normally considered only by the stipulation that the nominal weld-metal chemistry be the same as that of the alloy material being welded. No separate high-temperature allowable stresses are usually established for weld metal since it is generally assumed that weld metal of the same nominal chemistry as the base material, and having similar room-temperature properties, will also have comparable high-temperature properties. Test data on the molybdenum and chromium-molybdenum grades have indicated that this is a reasonable assumption since the strength of these grades is mainly dependent upon the nominal chemical composition and is relatively independent of thermal treatment or the microstructure of the weld material.

In the case of the vanadium-containing Cr-Mo base metals and weld metals, however, heat treatment and the microstructure resulting therefrom, are of major importance in establishing high-temperature properties.

The welding of the Cr-Mo-V steels for high-temperature service, therefore, requires the consideration of these factors, in addition to those involved in the fabrication of the conventional chrome-molybdenum steels.

Cr-Mo-V Base Metal

Before considering the electrodes used to fabricate components of Cr-Mo-V base material, the basic properties of the Cr-Mo-V material, as well as some of the metallurgical considerations encountered during the welding of this material, will be presented.

Pipe, casting and forging components have been made of Cr-Mo-V base metal and processed for high-temperature service. Their sizes have varied from small, several hundred-pound forgings to large, eighty thousand-pound castings. The nominal compositions of the cast and wrought forms of this material are given in Table 1. It should be noted that the casting composition has higher carbon and manganese contents than the wrought composition. This provides increased hardenability for the larger section sizes normally encountered with the cast components such as steam turbine shells.

The chromium-molybdenum-vanadium steels for high-temperature service are used in the normalized and tempered heat-treated condition as shown in Table 1. The desired structure of these compositions for long-time, high-temperature (1000 to 1050° F—100,000 hr) rupture strength is tempered bainite. Tempered martensite and structures containing excessive amounts of ferrite have lower rupture strengths in the above range. Figure *a* illustrates the tempered bainitic structure of a 6-in. casting test coupon. Figure *b* illustrates the tempered bainitic structure of a 2½-in. forging test section containing

R. J. Christoffel and F. H. Domina are in the Welding Unit, Materials and Processes Laboratory, and R. M. Curran and C. H. Soldan are in Materials Engineering, Large Steam Turbine-Generator Department, General Electric Co., Schenectady, N. Y.

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Table 1—Nominal Chemical Composition, Heat-Treatment Temperatures and Typical Physical Properties of Cr-Mo-V Base Materials

	Nominal chemical analysis, wt %					Heat treatment, °F		Room-temperature properties				
Form	C	Cr	Mo	V	Mn	Normalize	Temper	Tensile strength, psi	0.02% yield strength, psi	Elongation in 2 in., %	Reduction in area, %	Hardness, Brinell
Casting	0.18	1.00	1.00	0.20	0.70	1920*	1250†	95,000*	60,000*	15*	45*	200-240
Pipe	0.15†	1.00	1.00	0.20	0.45	1875*	1275*	60,000*	25,000*	15*		
Forging	0.15	1.00	1.00	0.20	0.45	1875*	1275*	80,000*	45,000*	15*	25*	175-225

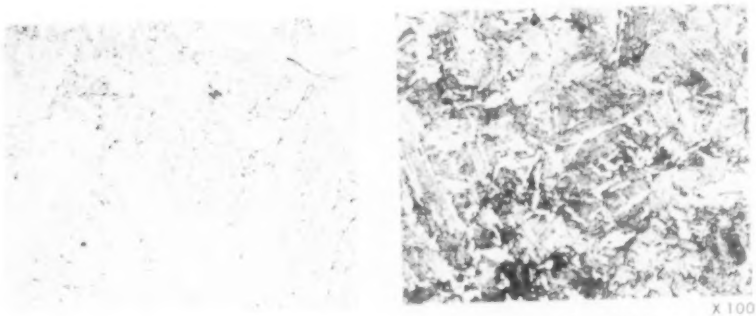
* Minimum values.
† Maximum value.

a small amount of ferrite. The acicular pattern of the forging microstructure indicates a lower transformation bainite as compared to the upper bainitic structure of the casting test section. This difference is attributed to the slower cooling rates normally obtained in the heavier casting sections. The small ferrite content of the forging test section is due to its lower hardenability as previously pointed out.

After normalizing, the compositions are tempered to the room-temperature properties shown in Table 1. The high-temperature rupture strengths typical of these Cr-Mo-V steels after normalize and temper are illustrated in Fig. 2. The results are plotted using the Larson-Miller parameter which is defined in Reference 3. Figure 2 indicates the improved high-temperature rupture strength of normalized and tempered Cr-Mo-V vs. the 2¼% Cr-1% Mo composition.[7]

Turbine construction requires the fabrication of heavy sections and welds having considerable restraint and a high level of residual stresses is common. It has been found necessary to maintain a minimum preheat of 450° F during all welding operations. Selection of this preheat level is based on hardenability and transition-temperature considerations. Further details concerning the use of preheat in welding Cr-Mo-V castings are given in Reference 1.

A heat treatment following welding is necessary to relieve the residual welding stresses and to temper the hard heat-affected zones created by the welding thermal cycle. This can be accomplished either by a subcritical stress-relief heat treatment or by subjecting the weldment to a normalizing and tempering operation. In a subcritical postweld heat treatment, the relief of residual stresses is accomplished by subjecting the weld to a high temperature where it has a lower yield strength. The lowering of the yield strength produces stress relief by plastic flow. Further stress relaxation is also accomplished by creep during time spent at the elevated temperature. However, for reduction of residual welding stresses, temperature is a more im-



a. Microstructure of 6-in. thick casting. X 100 b. Microstructure of 2½-in. thick forged pipe X 100

Fig. 1 Typical microstructures of Cr-Mo-V base metal in the normalized-and-tempered condition. (Reduced by ⅓ upon reproduction)

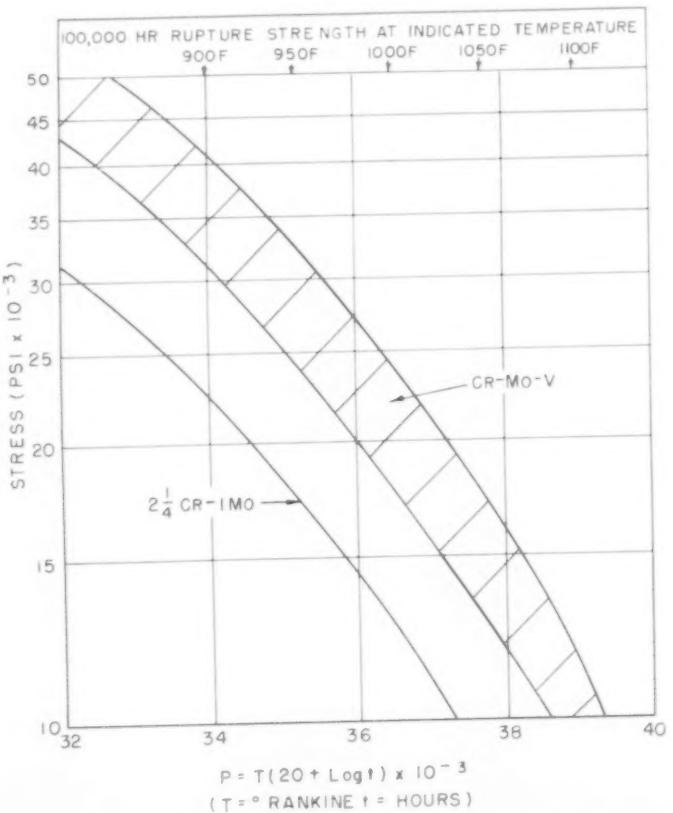


Fig. 2 Rupture-strength scatter band of cast Cr-Mo-V base metal compared to master curve for annealed 2¼ Cr-1Mo material[7]

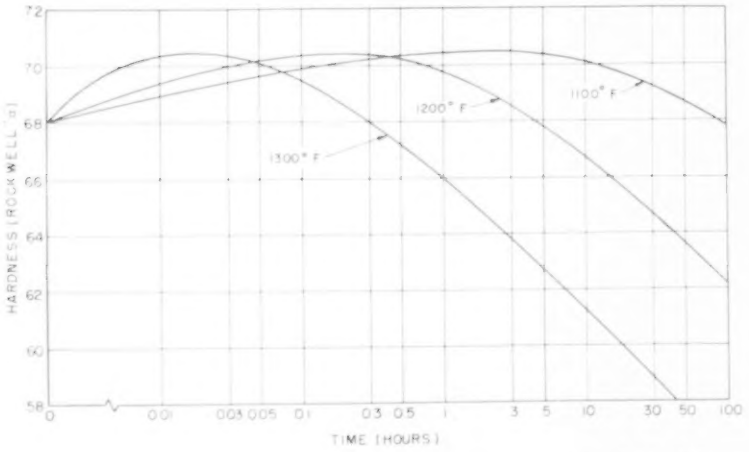


Fig. 3 Typical tempering response at various temperatures of cast Cr-Mo-V heat-affected zone

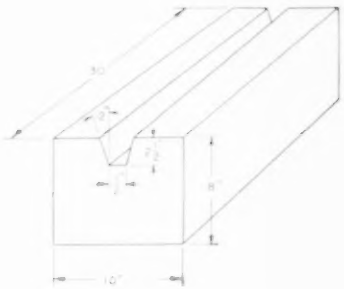


Fig. 4 Dimensions of keel block test showing groove preparation

portant factor than time.

With regard to the tempering action of the subcritical postweld heat treatment, the heat-affected zones of Cr-Mo-V base metals are subject to secondary hardening. Because of this, the heat-affected zone could be tempered to a hardness which is greater than that of the as-welded condition. The proper postweld heat treatment must, therefore, be designed with due cognizance of this phenomenon. Figure 3 illustrates the tempering curves for a Cr-Mo-V base-metal heat-affected zone. It will be noted that the time at temperature is an important variable and has to be controlled as well as the temperature. Present practice is to temper the heat-affected zone to a hardness which is below the as-welded condition and which approaches that of the adjacent unaffected base metal.

In a normalize-and-temper postweld heat treatment, all residual welding stresses and the heat-affected zones are completely eliminated because of the phase change occurring during the heat treatment. The selection of the type of postweld heat treatment given weldments in Cr-Mo-V base metal will be discussed in more detail throughout this paper as well as in Reference 1.

Welding Cr-Mo-V Base Metal (Electrode Selection)

Prior to using the 1% Cr – 1% Mo – ¼% V base metal, procedures were developed and qualified for manual metal-arc and submerged-arc welding the 1% Mo and 1% Cr – 1% Mo base metals using a 1% Mo and a ½% Cr – 1% Mo electrode. Since the ½% Cr – 1% Mo electrode produced satisfactory results with the 1% Cr – 1% Mo base metal, a manual metal-arc electrode of this composition with the addition of ¼% V was procured and qualified for welding the 1% Cr – 1% Mo – ¼% V base metal. The introduction of this Cr-Mo-V base metal, however, realized its greatest potential in the larger turbine components such as valves and shells, and the submerged-arc welding process is utilized to a great extent in welding these larger components. Therefore, ⅛-in. diam submerged-arc electrode of the ½% Cr – 1% Mo – ¼% V composition was also obtained to qualify a procedure similar to that used previously on the Cr-Mo metals. This procedure consisted of welding a butt joint between restrained 2-in. thick plates.

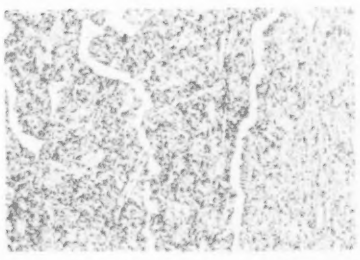
The first production welds made with the submerged-arc process, however, showed indications of transverse cracks in the weld metal when X-rayed after a postweld stress-relief heat treatment of 8 hr at 1275° F. Further examination showed extensive transverse cracking approximately 1 in. below the surface of the weld. Visual examination of samples taken from the weld showed that the cracking was largely confined to the "as-cast" position of the weld beads and not the recrystallized area which is produced by a subsequent bead. Metallographic examination also showed that the cracking appeared to have propagated along the columnar grain boundaries resulting during the original solidification.

Although no transverse cracking had been found in welded joints in the as-welded condition prior to this time, production welding was discontinued and an investigation conducted to determine the factors which might influence cracking such as the welding variables, effect of a postweld stress relief vs. a normalize-and-temper heat treatment and electrode composition.

Two half steam-chest castings were prepared and welded together using the ½% Cr – 1% Mo – ¼% V electrode. After welding, a 6-in. length of weld

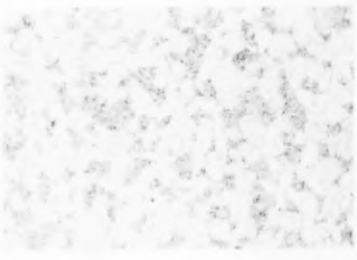
X100 Etch: 2% Nital

Fig. 5 ½ Cr–1Mo weld deposit in the as-welded condition. (Reduced by ⅓ upon reproduction)



X100 Etch: 2% Nital

Fig. 6 ½ Cr–1Mo weld deposit made from an 0.18% carbon electrode showing elongated ferrite. (Reduced by ⅓ upon reproduction)



X100 Etch: 2% Nital

Fig. 7 ½ Cr–1Mo weld after a normalize-and-temper heat treatment. (Reduced by ⅓ upon reproduction)

Table 2—Rupture Strength of Various Weld Metals

Material, wt %	Heat treatment	100,000-hr rupture strength, 900° F	1000° F	1050° F
½Cr–1Mo–¼V	8 hr at 1275° F	30,000	14,500	8,000
½Cr–1Mo–¼V	(8 hr at 1925° F, 28 hr at 1275° F)	26,000	16,000	12,000
½Cr–1Mo	8 hr at 1275° F	26,000	14,000	9,000
1¼Cr–½Mo	8 hr at 1275° F	30,000	13,000	6,500
2¼Cr–1Mo	8 hr at 1275° F	29,000	15,000	9,500
1Cr–1Mo–¼V (base metal)	(8 hr at 1925° F, 28 hr at 1275° F)	35,000	22,000	15,500

Table 3—Analysis of ½% Cr–1% Mo Electrode and Weld Deposits

Source	C	Mn	P	S	Si	Cr	Mo
Metal-arc deposit	0.11	0.60	0.020	0.025	0.77	0.48	0.90
Submerged-arc deposit	0.11	0.90	0.020	0.020	0.79	0.59	0.94
Submerged-arc electrode	0.23	0.51	0.020	0.019	0.41	0.58	1.07

was removed from one joint and cut into longitudinal slices, approximately ½ in. thick, parallel to the face of the weld. Macrosections of the individual slices were prepared showing no evidence of transverse cracking in the as-welded condition.

The section where this weld was removed was then rewelded by metal-arc welding using the ½% Cr – 1% Mo – ¼% V electrode and the weldment was given the regular stress-relief heat treatment of 1275° F for 8 hr. A 6-in. specimen was removed from each of the steam-chest joints and prepared as before. Numerous transverse cracks were found in both the weld metal and the base metal. The cracking was limited to the central region of the weldment with sections near the face and root of the weld being free from cracking.

A second groove was then welded with the submerged-arc process using the ½% Cr–1% Mo–¼% V electrode. The weldment was then given a full heat treatment which consisted of normalizing at 1925° F for 12 hr, air cool to 500° F, and tempering at 1275° F for 42 hr. A 6-in. section was removed as before and no evidence of cracking was found.

When the above procedure was repeated using the ½% Cr – 1% Mo electrode, careful examination showed the weld to be free of cracks. The results of the previous investigations may be summarized as follows:

1. No transverse cracks were found in the "as-welded" condition.

2. Transverse cracks were found after stress relieving welds made with the ½% Cr–1% Mo–¼% V electrode.

3. No transverse cracks were found after stress relieving submerged-arc welds with the ½% Cr – 1% Mo electrode.

4. No transverse cracks were found after normalizing and tempering of submerged-arc welds made with ½% Cr–1% Mo–¼% V electrode.

5. Transverse cracking, when it did occur, was confined largely to the weld metal, but a number of cracks appeared in the base metal adjacent to the joint.

It was evident that one solution to the production problem would be to give the castings a full heat treatment after welding. Inasmuch as this procedure was impractical in some instances and not always necessary, an investigation was conducted to determine the rupture properties of various electrodes which did not contain vanadium. In addition, the original procedure qualification made with 2-in. thick plates was shown to be inadequate due largely to the lack of restraint. Therefore, it was necessary to find a test which would produce the same results as those encountered in heavily restrained production welds.

Cast blocks 8 x 10 x 30 in. long were prepared with a 2½-in. deep groove, having a root space of ½ in. and 12-deg sidewalls. The dimensions of this block and the weld preparation used are shown in Fig. 4. These blocks were welded with

COMPOSITION VARIABLES

#1 - 0.09C; 0.16V, 0.48MN
#2 - 0.13C; 0.22V, 0.59MN
#3 - 0.21C; 0.19V, 0.57MN
#4 - 0.21C; 0.21V, 0.61MN
#5 0.27C; 0.21V, 0.64MN
#6 0.21C; 0.18V, 1.48MN

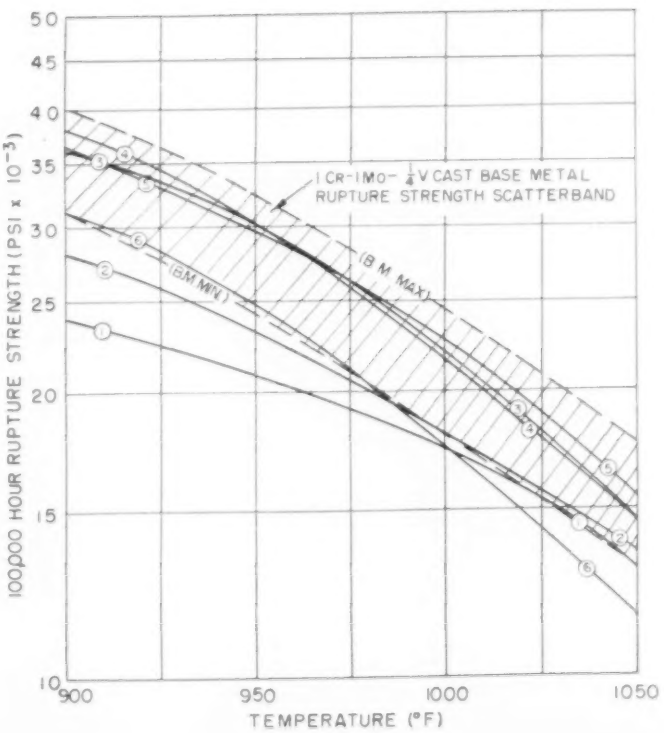


Fig. 8 Rupture strength of 1% Cr–1% Mo–¼% V development weld-metal compositions

Table 4—Chemical Composition of Development Weld Metals

	Composition, wt %							
Code	C	Mn	Si	P	S	Cr	Mo	V
1	0.09	0.48	0.42	<0.02	0.028	0.92	0.92	0.16
2	0.13	0.59	0.53	<0.02	0.021	0.99	0.98	0.22
3	0.21	0.57	0.36	<0.02	0.026	0.86	0.85	0.19
4	0.21	0.61	0.62	<0.02	0.020	1.02	1.04	0.21
5	0.27	0.64	0.68	<0.02	0.018	1.03	1.02	0.21
6	0.21	1.48	0.48	<0.02	0.022	1.05	1.00	0.18

the ½% Cr – 1% Mo – ¼% V electrode using both the manual metal-arc and the submerged-arc processes. After welding, each block received a postweld stress-relief heat treatment. The results of the welds made in the keel blocks with ½% Cr – 1% Mo – ¼% V electrode (both metal arc and submerged arc) substantiated the previous results since transverse cracking was found in both welds when using this composition. Therefore, it was felt that this was a satisfactory method of qualifying a procedure for heavily restrained weldments and this type test is still being used. Longitudinal bend tests were also added to the standard tests made for such a qualification to provide a better means for detecting transverse cracking. This consists of preparing a series of specimens 5 x 4 x ⅜ in. taken from the top to the bottom of the groove parallel to the face of the weld as described previously. These specimens are then tested in a guided bend fixture with the axis of the bend transverse to the welding direction.

During the time that this investigation was being conducted, the rupture tests made from the ½% Cr – 1% Mo, ½% Cr – 1% Mo – ¼% V, 1–¼% Cr – ½% Mo and the 2–¼% Cr – 1% Mo weld deposits were completed. Table 2 shows typical 100,000-hr rupture-strength values for the various electrodes at 900, 1000 and 1050° F.

When plotted, the rupture-strength curves of these electrodes all fall in a narrow scatter band. The weld metal has approximately 60% of the rupture strength of the base metal at 1000 and 1050° F in the stress-relieved condition. The strength of the ½% Cr – 1% Mo – ¼% V electrode is improved in the normalized-and-tempered condition. However, it is still lower than the base metal as shown in Table 2. Since the above test results show that the weld deposits of the ½% Cr – 1% Mo electrode have high-temperature properties comparable to the other electrodes and freedom from cracks after a stress-relief heat treatment, it was decided to utilize this electrode for welding the Cr-Mo-V base metal and to design the joints to compensate for the lower weld strength until future electrode-development programs would produce an electrode with properties similar to the base metal.

During the time in which the development work leading to the present Cr-Mo-V electrodes has been conducted, the ½% Cr – 1% Mo electrode has been successfully used to weld steam chests, valves, piping and other components made from the Cr-Mo-V base metal. In addition, the repair welding of large Cr-Mo-V castings with this electrode has also been highly successful. A few remarks regarding the chemistry and microstructure of this electrode follow, as it is one which is not available commercially.

The chemistry of typical weld deposits made from the ½% Cr – 1% Mo electrode is presented in Table 3. The chemistry of the submerged-arc electrode from which the deposit was made is also presented to show the variation in chemistry between the electrode and the deposit. The microstructure of the submerged-arc deposit in the as-welded condition, which is largely bainitic, is shown in Fig. 5.

It should be noted from Table 3 that the carbon loss across the arc in submerged-arc welding is approximately 50%. It has been found necessary to maintain a carbon level of 0.20–0.25% in the electrode to minimize the ferrite in the weld deposit. There is a tendency for this ferrite to occur in stringer form which is susceptible to cracking, particularly in the craters. A microstructure of such a deposit made from an electrode which contained 0.18% carbon is shown in Fig. 6.

The microstructure of a typical ½% Cr – 1% Mo weld deposit following the normalize-and-temper heat treatment is also presented in Fig. 7 as a basis for comparison with future electrodes and the base metal. The structure of the weld is largely ferrite with approximately 25–30% of a high transformation bainite.

Extensive exposure of samples of ½% Cr – 1% Mo welds at 1100° F have shown that the ½% chromium provides adequate insurance against graphitization. Graphitization in low-alloy steels is mainly a function of the acid-soluble aluminum content and the oxidizing nature of the welding are ensures that the aluminum content of

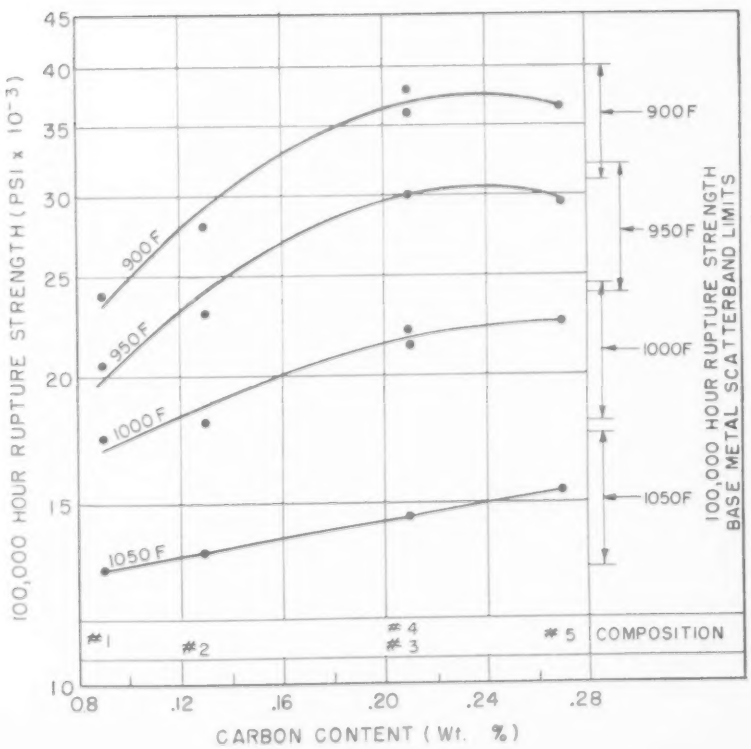


Fig. 9 Effect of carbon content on rupture strength

Table 5—Rupture Strength of Development Weld Metals

Code	Composition variable, wt % C	Mn	Heat treatment*	100,000-hr rupture strength, psi 900° F	950° F	1000° F	1050° F
1	0.09	0.48	N. and T.	24,000	20,500	17,300	13,000
2	0.13	0.59	N. and T.	28,000	25,000	18,000	13,500
3	0.21	0.57	N. and T.	36,000	30,000	22,000	14,500
3	0.21	0.57	S. R.	34,000	25,000	15,000	9,000
4	0.21	0.64	N. and T.	38,000	30,000	21,500	14,500
5	0.27	0.64	N. and T.	36,500	29,500	22,500	15,500
6	0.21	1.48	N. and T.	31,000	24,500	17,500	11,500
Cr-Mo-V base metal Scatter band			Max	40,000	32,000	24,500	17,500
			Min	31,000	24,000	18,000	13,000

* N. and T.—Normalized and Tempered; S. R.—Stress Relieved.

the deposit will be maintained at an extremely low level. Long-time exposure of all weld deposits, including those free of chromium, have shown them to be remarkably resistant to graphitization.

Cr-Mo-V Electrode Development

The low rupture strength exhibited by the Cr-Mo-V weld deposits in the stress-relieved condition as previously pointed out in Table 2 is not surprising since it is known that the normalizing treatment is necessary to develop high-temperature properties in the base material. The low rupture strength of the normalized weld deposits, however, was not anticipated. It appeared that there were two possible explanations: (1) the vanadium might have formed oxides or nitrides during transfer across the arc, and hence, not be available as a high-temperature strengthener, and (2) due to its lower carbon content and inherently finer grain size, the hardenability of the weld deposit was lower than that of the base metal and the structure of the normalized-and-tempered weld metal contained considerably more ferrite than present in the base metal.

When an investigation showed no nitrides or oxides of vanadium present in the weld metal, it was concluded that the lower strength exhibited by the Cr-Mo-V was due solely to its lack of adequate hardenability.

An initial study was conducted with a series of molybdenum-vanadium electrodes containing sufficient chromium and manganese to achieve a hardenability equal to, and greater than, that of the base metal. The carbon in these deposits was approximately 0.10%, as commercial electrodes of the compositions did not contain sufficient carbon to provide for the carbon loss previously mentioned with the submerged-arc process and retain a higher level in the deposit. While the structure of these weld deposits was completely bainitic and similar to that of the base material, no major improvement in rupture strength was obtained. While these tests did not encompass all of the possible combinations of alloying elements, they did indicate that for a nominal composition of 1% Cr–1% Mo–¼% V, higher weld-metal strengths could probably be best achieved by increasing the carbon content despite the problems this involved.

A second series of development compositions was investigated with the chromium and molybdenum contents fixed at 1% and the vanadium content at approximately ¼%. The carbon content was varied over the range of 0.1 to 0.3%, and manganese was studied at the normal level of 0.6% and the higher level of 1.5%. The chemical analysis of the six development weld-metal compositions investigated are listed in Table 4. To obtain rupture test specimens each electrode composition was used to weld a groove 2" in. wide between two restrained plates of 1% Cr–1% Mo–¼% V base metal, each 3 in. wide, 1 in. thick and 10-12 in. long. The welding was done by the manual metal-arc process using ⅛-in.

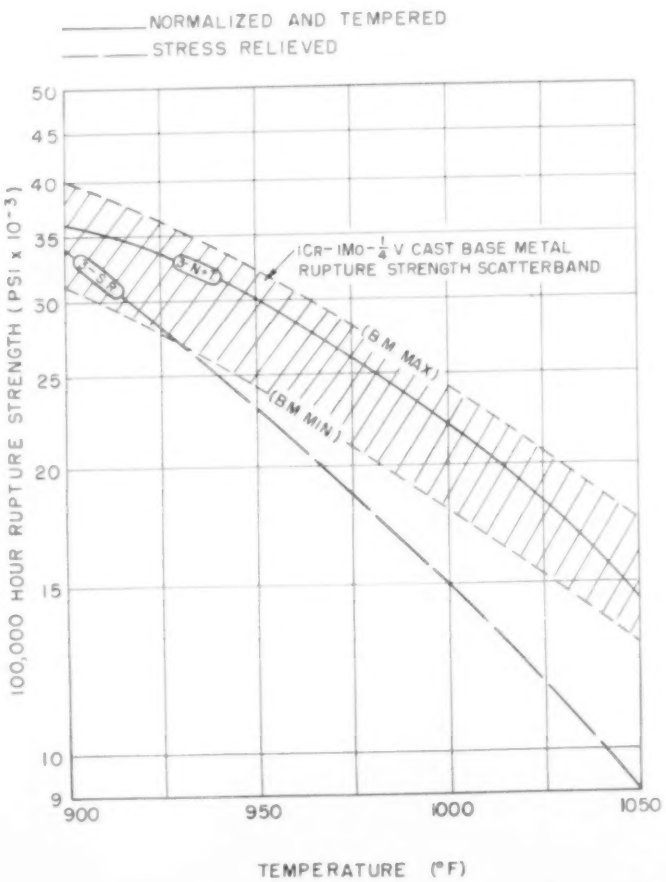


Fig. 10 Effect of heat treatment on rupture strength of Composition 3

diam electrode with a preheat of 500° F and a maximum interpass temperature of 750° F. The welds were periodically magnetic-particle tested for cracking, and no cracking was detected.

After welding, the plates were removed from the restraining fixture and given a normalize-and-temper heat treatment. The test plates were attached to a large casting for this heat treatment to assure that the cooling rate from the austenitizing temperature would be comparable to that of an actual weld in a large casting. This heat treatment consisted of austenitizing at 1925° F for 12 hr, air cooling to at least 550° F and then tempering for 28 hr at 1274° F followed by a furnace cool. In addition, a portion of the plate welded with Composition 3 was given only a postweld stress-relief heat treatment consisting of 8 hr at 1274° F and then furnace cooled.

Cross-weld rupture test specimens were then removed from each plate in such a manner that the 2-in. gage length of the test specimen contained only weld metal. Rupture tests were conducted for all compositions and the data were plotted for analysis purposes using the Larson-Miller parameter method. The 100,000-hr rupture strength at temperatures of 900, 950, 1000 and 1050° F for each composition, as determined from the parameter plots of the data, is listed in Table 5.

The results obtained are also shown in Fig. 8 which is a plot of the 100,000-hr rupture strength vs. temperature in the range of 900 to 1050° F. Composition 1 serves as a base Cr-Mo-V weld-metal composition with a carbon content (0.09%) which is in the range of conventional weld deposits. The rupture strength of this composition is the lowest shown in Fig. 8 (neglecting number 6 in the 1050° F range for the moment), and it just barely equals the minimum base-metal strength in the range of 1025 to 1050° F. When the carbon was increased in Composition 2, the rupture strength increased and the strength of the composition entered the base-metal scatter band at 1000° F, but it was still in the very bottom of the base metal range. Increasing the carbon content to 0.21% in both Compositions 3 and 4 produced still further increase in rupture strength, and the rupture strength of these two compositions fell in the upper half of the base-metal scatter band. This strength is also well above that obtained for conventional commercial weld deposits. With a still further increase in carbon content to 0.27% in Composition 5, there was essentially no additional increase in rupture strength. This indicated that for the 1% Cr–1% Mo–¼% V composition the optimum carbon content was approximately 0.2%. The effect of carbon content on rupture strength can be seen quite readily in Fig. 9, and it will be noted from this figure that the effect is more pronounced at lower temperatures such as 900° F than at 1050° F. The results obtained in this phase of the investigation indicate that the increase in rupture strength in compositions such as Nos. 3 and 4, compared to the strength of conventional commercial electrodes, is due not only to the presence of carbide-forming elements in the deposit, but also sufficient carbon actually to form the stable alloy carbides.

Table 6—Chemical Composition

	Composition, wt %							
	C	Mn	Si	P	S	Cr	Mo	V
Weld	0.17	0.62	0.56	<0.02	0.016	1.12	0.90	0.22
Base	0.17	0.64	0.36	0.008	0.009	1.10	0.92	0.19

The effect of manganese can be seen by comparing the results obtained for Composition 6 with those for Compositions 3 and 4. These three compositions are similar in all respects except for their manganese content. Composition 6 had 1.48% manganese while Composition 3 had 0.57% and Composition 4 had 0.61%. It can be seen from Fig. 8 that the increase in manganese reduced the rupture strength significantly at all temperatures.

The effect of heat treatment on rupture strength was found by comparing the rupture test results obtained for Composition 3 in the normalized-and-tempered and in the stress-relieved conditions. These results are shown in Fig. 10, and it can be seen that the rupture strength in the stress-relieved condition is lower than that in the normalized-and-tempered condition. At testing conditions equivalent to 100,000 hr at 900° F, the difference between the two heat treatments is not great, and the rupture strength in the stress-relieved condition actually falls in the base-metal scatter band. However, at higher temperatures, the rupture strength of the weld metal in the stress-relieved condition falls off faster and drops below the base-metal scatter band. The rupture strength of Composition 3, which in the normalized-and-tempered condition falls in the base-metal scatter band over the entire temperature range investigated, is actually not much better in the stress-relieved condition than the ½% Cr–1% Mo weld metal.

To summarize, the results obtained from the development compositions indicate that a weld-metal composition of approximately 0.2% carbon, 1% chromium, 1% molybdenum, ¼% vanadium, and manganese at the usual level of 0.6%, in the normalized-and-tempered condition would have a rupture strength comparable to that of the Cr-Mo-V base metal. It was therefore decided to obtain a production size lot of 0.2% C–1% Cr–1% Mo–¼% V electrode to evaluate fully the properties of this electrode composition and to qualify a procedure for welding heavy sections of Cr-Mo-V base metal with this electrode.

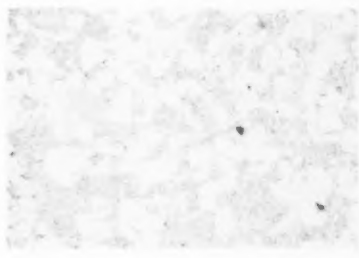
Evaluation of 0.2% C – 1% Cr – 1% Mo – ¼% V Electrode

To determine the ability to deposit a

a X200

b X1000

Fig. 11 Microstructure of 1Cr–1Mo–¼V weld metal in the as-welded condition. Etch: 2% Nital. (Reduced by ⅓ upon reproduction)



X100 Etch: 2% Nital

Fig. 12 Microstructure of 1Cr–1Mo–¼V weld metal in the normalized-and-tempered condition. (Reduced by ⅓ upon reproduction)

satisfactory weld in the 1% Cr – 1% Mo – ¼% V base metal using the 0.2% C – 1% Cr – 1% Mo – ¼% V manual metal-arc electrode, and to evaluate the properties of the weld metal and welded joint, two grooves in a Cr-Mo-V test block were welded using this electrode. Welding was done using ⅛-in. diam electrodes at a minimum preheat of 450° F and a maximum interpass temperature of 750° F. The weld deposit was inspected periodically by magnetic-particle testing and no defects were encountered. Samples were removed to determine the hardness and microstructure in the as-welded condition. After welding, the test block was given a normalize-and-temper heat treatment consisting of austenitizing at 1925° F for 12 hr and air cooling to at least 550° F, tempering for 28 hr at 1274° F and then a furnace cooling to room temperature. Material from the welded and heat-treated block was used to obtain tensile, bend, rupture and creep specimens as well as samples for chemical analysis, hardness determinations and metallographic examination. Prior to testing, magnetic-particle inspections were made of all specimens and the creep-and-rupture specimens were also radiographed. No cracking was detected.

The results of the chemical analysis of the weld metal are shown in Table 6 as well as the chemical composition of the test block used in this portion of the investigation.

The microstructure of the weld metal in the as-welded condition at low and high magnifications is shown in Figs. 11*a* and 11*b*. The structure in the as-welded condition is a fine bainite with no free ferrite. The microstructure of the weld metal in the normalized-and-tempered condition is shown in Fig. 12, and it can be seen that it is fine grained and approximately 50% bainite and 50% proeutectoid ferrite.

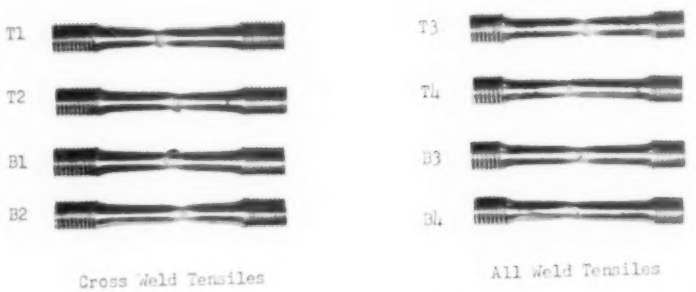
The hardness of the weld metal in the as-welded condition was found to be 68 R_A (330 Brinell). The hardness of the weld metal in the normalized-and-tempered condition was found to be 55 Rockwell "A" while the Cr-Mo-V base metal, which received the same heat treatment, had a slightly higher hardness of 58 Rockwell "A."

The longitudinal and side-bend samples tested satisfactorily and a typical sample of each is shown in Fig. 13. The free-bend samples tested satisfactorily with elongations obtained in the range of 50 to 90%. A typical example is shown in Fig. 13. The results obtained for the all-weld and cross-weld tensile tests are shown in Fig. 13. The tensile and yield strengths of the weld metal were equal to or slightly below the minimum requirements of 95,000 psi tensile strength and 60,000 psi yield strength for the Cr-Mo-V cast base metal.

Table 7—Rupture Test Results for Cr-Mo-V Weld Metal in the Normalized-and-Tempered Condition

Temperature, °F	*Stress, kpsi*	*Time, hr*	*Elongation, %*	*Reduction of area, %*	*P* (*K* 10⁻³)	*Fracture location*
			All-weld specimens			
1100	34	140	17	78	32.3	
1100	30	32	19	80	33.5	
1100	27	96	16	79	34.2	
1050	26	948	11	50	34.7	
1050	24	1911	7.9	47	35.1	
1200	20	124	9.9	40	36.6	
1200	15	573	11	32	37.7	
1300	10	144	10.9	52	38.9	
			Cross-weld specimens			
1050	30	810	12	71	34.6	Weld
1050	29	986	11	63	34.7	Weld
1100	27	115	15	74	34.4	Weld
1200	22	41	16	71	35.8	Base
1200	19	120	10	56	36.6	Weld
1200	15	689	10.7	37	37.9	Base
1300	10	164	6	33	39.0	Base

The results of the all-weld and cross-weld rupture tests are listed in Table 7 and plotted in Fig. 14 using the Larson-Miller parameter method of presentation. The Cr-Mo-V cast base-metal scatter band is also plotted in this figure, and it can be seen that the cross-weld rupture test results are completely within the base-metal scatter band. The all-weld results are within the base-



	% R.A.	Ultimate (psi)	Break Location		0.02% Yield (psi)	Ultimate (psi)	% R.A.	Elong. in 2" (%)
T1	54.7	91,100	Weld	T3	58,000	95,300	55.7	22.5
T2	42.2	90,000	Weld	T4	60,500	96,400	37.0	18.5
B1	47.2	92,000	Weld	B3	56,500	95,000	50.6	22.0
B2	55.2	92,500	Weld	B4	57,000	93,000	34.1	15.5

Fig. 13 Physical test specimens from normalized-and-tempered Cr-Mo-V keel block weldment

metal scatter band at parameter values equivalent to 100,000 hr at 950° F and above, but they are below the base-metal scatter band at lower parameter values.

The creep strength of the weld metal as indicated by the stress level required to produce a creep extension of 1 mil per in. is shown in Fig. 15. These data are also plotted using the Larson-Miller parameter method. The Cr-Mo-V cast base-metal scatter band is shown in this figure and it can be seen that the weld metal has creep strength comparable to that of the base metal.

The results obtained from this phase of the investigation indicate that the Cr-Mo-V base metal can be welded satisfactorily with the nominal 0.20% C, 1% Cr, 1% Mo, ¼% V weld-metal-composition electrode. The properties of this weld metal in the normalized-and-tempered condition were comparable to those of the base metal, so it should be possible to fabricate components for high-temperature service on an equal strength basis for both weld and base metals.

When compared with base-metal properties, the weld metal had slightly lower rupture strength at low parameter values. This is a reflection of the somewhat low room-temperature yield strength of the weld metal since the room-temperature yield strength will affect the rupture strength of a material at low parameter values. This difference between the weld and base metals can be explained by referring to the microstructure of the weld and base metals. As shown in Fig. 12, the microstructure of this particular weld deposit was a mixture of ferrite and bainite, whereas the base metal is generally fully bainitic. A fully bainitic structure will have a higher yield strength than one containing a large amount of ferrite. Therefore, the somewhat low room-temperature yield strength and rupture strength at low parameter values of the weld metal, compared to the base metal, are due to the large amount of ferrite which was present in the weld metal and which is not generally present in the base metal. The slightly lower strength of these deposits at the lower temperature levels, however, is not considered a deterrent to the use of this electrode in high-temperature service.

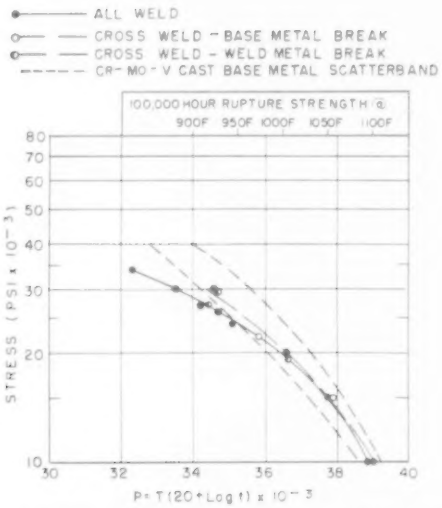


Fig. 14 Rupture strength of Cr-Mo-V weld metal in the normalized-and-tempered condition

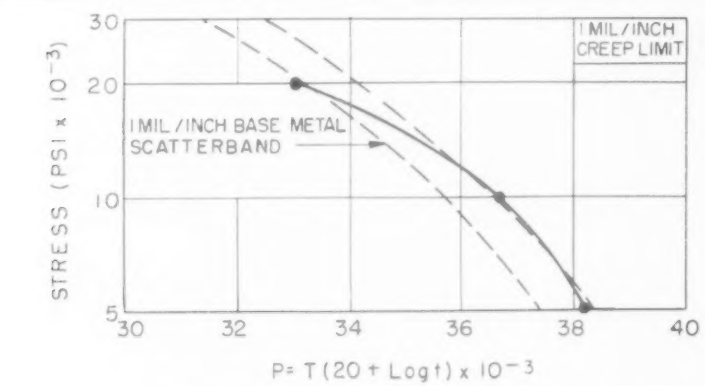


Fig. 15 Creep strength of Cr-Mo-V weld metal in the normalized-and-tempered condition

Summary

The investigations discussed and the experience of the authors' company indicate that:

1. The Cr-Mo-V base metal can be welded satisfactorily with a 1¼% Cr – 1% Mo electrode using preheat to prevent cracking. Welding is followed by either a normalize-and-temper or a subcritical stress-relief postweld heat treatment. If stress-relief heat treatment is used, the secondary hardening tendencies of the base-metal heat-affected zone must be considered. The rupture strength of the 2¼% Cr – 1% Mo weld metal in either heat-treated condition is lower than that of base metal, so design of critical welded sections is based on the weld-metal strength.

2. A Cr-Mo-V manual metal-arc electrode has been developed and qualified for welding the Cr-Mo-V base metal. The rupture strength of weld deposits made with this electrode in the normalized-and-tempered condition is comparable to that of the base metal. This weld metal should not be used with a stress-relief heat treatment as the full properties of the weld are not developed, and such a heat treatment can produce cracking.

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"When this paper was written, the authors included information and expressed opinions believed to be correct and reliable. Because of the constant advance of technical knowledge, the widely differing conditions of possible specific application, and the possibility of misapplication, any application of the contents of this paper must be at the sole discretion and responsibility of the user."

Acknowledgment

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STRESS RELIEVING OF STAINLESS STEELS AND THE ASSOCIATED METALLURGY

WRC interpretive report covers the major classifications of stainless steels—martensitic, ferritic and austenitic

BY R. A. HUSEBY

SUMMARY. Residual stresses frequently are present in stainless-steel structures that have been fabricated by conventional methods. The stainless steels and particularly the chromium-nickel grades have excellent cold-forming qualities and may be welded readily by most of the conventional methods, but such operations introduce residual stresses which may affect the serviceability of the material.

The mechanical properties of the austenitic chromium-nickel stainless steels appear to be only mildly affected by fabricating operations; however, residual stresses induced by such operations may drastically affect the behavior in certain corrosive environments (stress corrosion) and, also, the dimensional stability. Unfortunately, heating to the conventional range of temperature for stress relieving is within a temperature range that affects the microstructure and may result in a diminution of ductility, impact properties and general corrosion resistance. Consequently, stress relieving of the austenitic stainless steels usually is employed only for conditions where severe stress corrosion may be encountered, or for a high degree of dimensional stability. Under such conditions, consideration should be given to grades which are relatively insensitive to temperatures employed for stress relieving.

Thermal stress relieving of the ferritic chromium stainless steels after fabrication is necessary to obtain the desired mechanical properties and corrosion resistance. The microstructure resulting from welding or heating to intermediate temperatures is not conducive to good mechanical properties or corrosion resistance, hence the necessity for stress relieving or annealing after fabrication.

The martensitic stainless steels are highly hardenable. They require preheating and high interpass temperatures during welding and immediate postheating after welding to avoid cracking. The postheating temperature usually is the temperature required for stress relieving.

Thermal stress relieving, after welding the straight chromium stainless steels, is mandatory under most codes and is necessary to obtain the required level of mechanical properties and corrosion resistance. The mechanical properties of the austenitic chromium-nicked stainless steels are little affected by welding, although the corrosion resistance may be. Thermal stress relieving of the chromium-nickel grades may adversely affect mechanical properties and resistance to some types of corrosion, but is employed usually to resist stress corrosion and to reduce high locked-up stresses. The application, the type of alloy and the magnitude of the residual stresses are factors which determine whether stress relieving of chromium-nickel stainless steel is desirable. Before stress relieving the austenitic chromium-nickel stainless steels it should be ascertained that the steel will not be in a poorer condition to meet service requirements after stress relieving than if no thermal stress-relief treatment were applied.

Introduction

Stress relieving in its original concept was exactly what the name implies—a method of reducing residual stresses to a low level by heating. It is now well recognized that structural modifications of deposited metal and affected base metal, especially in alloy steels, are also of great importance. Figure 1 shows a family of curves where the residual stress remaining in a quenched steel bar is plotted against time at temperature for several post-heating temperatures. These curves, from Jasper's work in 1926,[1] showed that adequate stress relief of carbon-steel structures could be attained at temperatures where distortion would not be excessive.

Residual stresses frequently called "locked-up" stresses or "internal" stresses are those existing in a body free from external forces. They are developed to some degree by almost any fabricating procedure. Any process which effects a nonuniform change in shape or volume will create residual stress. Residual stresses are commonly divided into "macro" and "micro" stresses. Micro stresses balance themselves out over the order of magnitude of a few grain diameters. Macro stresses balance themselves out over larger distances. We are largely concerned with macro stresses in this report. The ordinary measurements by X-ray or mechanical methods reveal macro stress. Micro stress can be measured by X-ray using very specialized tech-

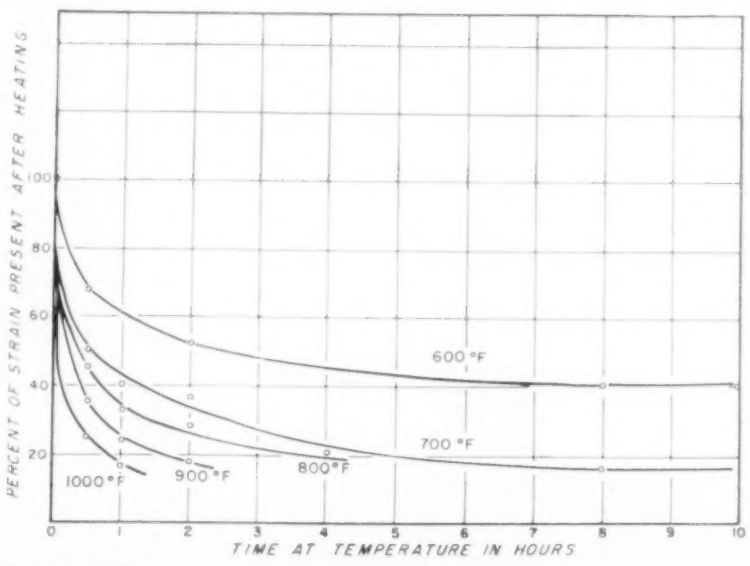


Fig. 1 Effect of heating time and temperature on relief of residual strain in mild steel

R. A. Huseby is associated with the Metallurgical Research Dept., A. O. Smith Corp., Milwaukee, Wis.

Table 1A—Standard Types of Stainless and Heat-Resisting Steels with Chemical Ranges and Limits

Subject to Variations for Check Analysis (Table 2)

Type Number	C	Mn Max	P Max	S Max	Si Max	Chemical Composition, % Cr	Ni	Mo	Zr	Se	Ti	Cb+Ta	Ta	Al	N
301	0.15 max	2.00	0.045	0.030	1.00	16.00 18.00	6.00 8.00								
302	0.15 max	2.00	0.045	0.030	1.00	17.00 19.00	8.00 10.00								
302B	0.15 max	2.00	0.045	0.030	2.00 3.00	17.00 19.00	8.00 10.00								
303	0.15 max	2.00	0.20	0.15 min	1.00	17.00 19.00	8.00 10.00	0.60* max	0.60* max						
303 Se	0.15 max	2.00	0.20	0.06	1.00	17.00 19.00	8.00 10.00			0.15 min					
304	0.08 max	2.00	0.045	0.030	1.00	18.00 20.00	8.00 12.00								
304L	0.03 max	2.00	0.045	0.030	1.00	18.00 20.00	8.00 12.00								
305	0.12 max	2.00	0.045	0.030	1.00	17.00 19.00	10.00 13.00								
308	0.08 max	2.00	0.045	0.030	1.00	19.00 21.00	10.00 12.00								
309	0.20 max	2.00	0.045	0.030	1.00	22.00 24.00	12.00 15.00								
309S	0.08 max	2.00	0.045	0.030	1.00	22.00 24.00	12.00 15.00								
310	0.25 max	2.00	0.045	0.030	1.50	24.00 26.00	19.00 22.00								
310S	0.08 max	2.00	0.045	0.030	1.50	24.00 26.00	19.00 22.00								
314	0.25 max	2.00	0.045	0.030	1.50 3.00	23.00 26.00	19.00 22.00								
316	0.08 max	2.00	0.045	0.030	1.00	16.00 18.00	10.00 14.00	2.00 3.00							
316L	0.03 max	2.00	0.045	0.030	1.00	16.00 18.00	10.00 14.00	2.00 3.00							
317	0.08 max	2.00	0.045	0.030	1.00	18.00 20.00	11.00 15.00	3.00 4.00							
321	0.08 max	2.00	0.045	0.030	1.00	17.00 19.00	9.00 12.00				5 x C min				
347	0.08 max	2.00	0.045	0.030	1.00	17.00 19.00	9.00 13.00					10 x C min			
348	0.08 max	2.00	0.045	0.030	1.00	17.00 19.00	9.00 13.00					10 x C min	0.10 max		
403	0.15 max	1.00	0.040	0.030	0.50	11.50 13.00									
405	0.08 max	1.00	0.040	0.030	1.00	11.50 14.50								0.10 0.30	
410	0.15 max	1.00	0.040	0.030	1.00	11.50 13.50									
414	0.15 max	1.00	0.040	0.030	1.00	11.50 13.50	1.25 2.50								
416	0.15 max	1.25	0.06	0.15 min	1.00	12.00 14.00		0.60* max	0.60* max						
416 Se	0.15 max	1.25	0.06	0.06	1.00	12.00 14.00				0.15 min					
420	Over 0.15	1.00	0.040	0.030	1.00	12.00 14.00									
430	0.12 max	1.00	0.040	0.030	1.00	14.00 18.00									
430F	0.12 max	1.25	0.06	0.15 min	1.00	14.00 18.00		0.60* max	0.60* max						
430F Se	0.12 max	1.25	0.06	0.06	1.00	14.00 18.00				0.15 min					
431	0.20 max	1.00	0.040	0.030	1.00	15.00 17.00	1.25 2.50								
440A	0.60 0.75	1.00	0.040	0.030	1.00	16.00 18.00		0.75 max							
440B	0.75 0.95	1.00	0.040	0.030	1.00	16.00 18.00		0.75 max							
440C	0.95 1.20	1.00	0.040	0.030	1.00	16.00 18.00		0.75 max							
446	0.20 max	1.50	0.040	0.030	1.00	23.00 27.00									0.25 max

* At producer's option; reported only when intentionally added.

Table 1B—Alloy Casting Institute Standard Designations and Chemical Composition Ranges for Heat 1 and Corrosion-Resistant Castings

Cast alloy designation	Wrought alloy type (see note A)	Composition, % (balance Fe)							
		C	Mn max	Si max	P max	S max	Cr	Ni	Other elements
CA-15	410	0.15 max	1.00	1.50	0.04	0.04	11.5-14	1 max	Mo 0.5 max†
CA-40	420	0.20-0.40	1.00	1.50	0.04	0.04	11.5-14	1 max	Mo 0.5 max†
CB-30	431	0.30 max	1.00	1.00	0.04	0.04	18-22	2 max	
CC-50	446	0.50 max	1.00	1.00	0.04	0.04	26-30	4 max	
CE-30		0.30 max	1.50	2.00	0.04	0.04	26-30	8-11	
CF-8	304	0.08 max	1.50	2.00	0.04	0.04	18-21	8-11	
CF-20	302	0.20 max	1.50	2.00	0.04	0.04	18-21	8-11	
CF-8M	316	0.08 max	1.50	1.50	0.04	0.04	18-21	9-12	Mo 2.0-3.0
CF-12M	316	0.12 max	1.50	1.50	0.04	0.04	18-21	9-12	Mo 2.0-3.0
CF-8C	347	0.08 max	1.50	2.00	0.04	0.04	18-21	9-12	Cb 8 x C min, 1.0 max, or Cb-Ta 10 x C min, 1.35 max
CF-16F	303	0.16 max	1.50	2.00	0.17	0.04	18-21	9-12	Mo 1.5 max, Se 0.20-0.35
CH-20	309	0.20 max	1.50	2.00	0.04	0.04	22-26	12-15	
CK-20	310	0.20 max	1.50	2.00	0.04	0.04	23-27	19-22	
CN-7M		0.07 max	1.50	*	0.04	0.04	18-22	21-31	Mo-Cu*
HA		0.20 max	0.35-0.65	1.00	0.04	0.04	8-10		Mo 0.90-1.20
HC	446	0.50 max	1.00	2.00	0.04	0.04	26-30	4 max	Mo 0.5 max†
HD	327	0.50 max	1.50	2.00	0.04	0.04	26-30	4-7	Mo 0.5 max†
HE		0.20-0.50	2.00	2.00	0.04	0.04	26-30	8-11	Mo 0.5 max†
HF	302B	0.20-0.40	2.00	2.00	0.04	0.04	19-23	9-12	Mo 0.5 max†
HH	309	0.20-0.50	2.00	2.00	0.04	0.04	24-28	11-14	Mo 0.5 max† N 0.2 max
HI		0.20-0.50	2.00	2.00	0.04	0.04	26-30	14-18	Mo 0.5 max†
HK	310	0.20-0.60	2.00	3.00	0.04	0.04	24-28	18-22	Mo 0.5 max†
HL		0.20-0.60	2.00	3.00	0.04	0.04	28-32	18-22	Mo 0.5 max†
HN		0.20-0.50	2.00	2.00	0.04	0.04	19-23	23-27	Mo 0.5 max†
HT	330	0.35-0.75	2.00	2.50	0.04	0.04	13-17	33-37	Mo 0.5 max†
HU		0.35-0.75	2.00	2.50	0.04	0.04	17-21	37-41	Mo 0.5 max†
HW		0.35-0.75	2.00	2.50	0.04	0.04	10-14	58-62	Mo 0.5 max†
HX		0.35-0.75	2.00	2.50	0.04	0.04	15-19	64-68	Mo 0.5 max†

* There are several proprietary alloy compositions falling within the stated chromium and nickel ranges, and containing varying amounts of silicon, molybdenum and copper. Such alloys are available from licensed producers only.

† Molybdenum not intentionally added.

Designations with the initial letter "C" indicate alloys generally used to resist corrosive attack at temperatures less than 1200° F. Designations with the initial letter "H" indicate alloys generally used under conditions where the metal temperature is in excess of 1200° F. The second letter represents the nominal chromium-nickel type; the nickel content increasing in amount from "A" to "X." For example, "F" stands for the 19%, Cr-9%, Ni, "K" for the 25%, Cr-20%, Ni, and "W" for the 12%, Cr-60%, Ni alloy types. Numerals following the letters indicate the *maximum* carbon content of the corrosion resistant alloys; carbon content may also be designated in the heat-resistant grades by following the letters with a numeral to indicate the *midpoint* of a ±0.10% carbon range. If special elements are included in the composition they are indicated by the addition of a letter to the symbol. Thus, "CF-8M" is an alloy for corrosion resistant service, of the molybdenum-containing 19%, Cr-9%, Ni type with a maximum carbon content of 0.08%.

NOTE A: Wrought alloy type numbers are listed only for the convenience of those who want to determine corresponding wrought and cast grades. Because the cast alloy chemical composition ranges *are not the same* as the wrought composition ranges, buyers should use cast alloy designations for proper identification of castings.

NOTE B: Most of the standard grades listed are covered for general applications by American Society for Testing Materials specifications A296-49T and A297-49T. ASTM specifications A217-49T, A351-52T, A362-52T, B190-50 and B207-50 also apply to some of the grades.

niques. Macro stress can be further subdivided into reaction stress and direct stress. Reaction stress, which is an important factor in welding restrained members, can be released by removing the restraint. Direct stress balances itself out in the immediate weld area. These designations are purely arbitrary for the metal lattice recognizes but one stress which can only be measured by the resulting strain. The classical laws of mechanics apply in dealing with residual stresses exactly as they do in load stresses with one important practical consideration. At the first loading, if the vector sum of residual and load stress exceeds the elastic limit, some measure of mechanical stress relief will occur. The combined stress pattern after loading or overloading may bear no resemblance to the original pattern. This is illustrated in Fig. 2.

Thermal stress relief depends on plastic flow or creep, which, in turn, is time-temperature dependent. Ductile materials with nonuniform residual stresses can be mechanically stress relieved by deforming the entire structure plastically as shown in Fig. 2. Mechanical stress relieving of this type is most useful in leveling out residual-stress peaks. It might be inferred from what has been said that residual stresses are always detrimental. Of course, this is not true. For example, by judicious cold work, which certainly imparts residual stress, large improvements in ultimate strength, yield strength and endurance limit are possible. The various methods of surface treatment to impart an increased endurance limit are generally known. These include shot peening, cold rolling and surface hardening, as well as numerous other processes. The improved endurance limit has been ascribed to the compressive residual surface stress resulting from the treatment. Actually, the residual compressive stress is usually accompanied by increased hardness and it is difficult to separate the two effects. However, some revealing work by Horger[2] showed increased endurance limit resulting where surface compressive stress was induced in railroad axles by quenching from 1000° F. Since no appreciable structural change took place, the

improvement in life must have been achieved by the induced surface compressive stress.

High stress gradients and reaction stresses may be dangerous and their reduction to a low level by stress relieving is often desirable. The salient feature of reaction stress is that it exists over a large area but can expend itself at a small section. In a truss the reaction stress can be released by cutting any one of the members. The direct welding stress remains even after the member is cut. Because reaction stresses can distribute themselves over a large structure, they are a high energy source which can expend themselves in the propagation of a fracture.

Stress concentration or high-stress gradients can best be illustrated by the photoelastic method which enables one to "see stresses." Figure 3 from some of the classic work of Levin and Frocht,[3] shows severe concentration existing when a notched specimen is loaded. By the photoelastic technique, strain is visible in a plastic model in the form of a series of interference bands, and the stress level is proportional to the number of bands (called fringes) which appear in loading the model. The fringes themselves are actually zones of constant shear strain. Since shear stress is proportional to the difference between the principal stresses

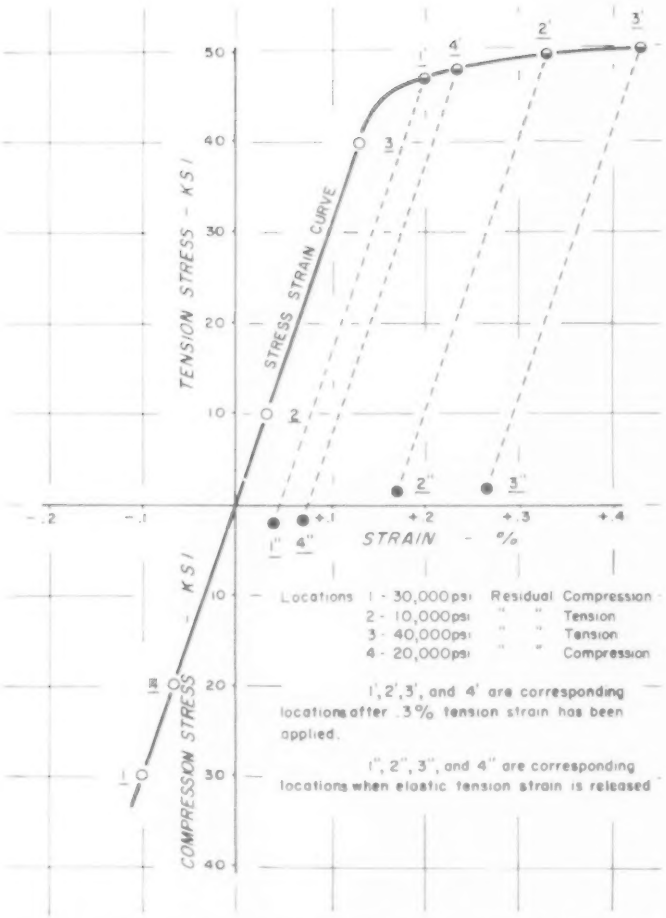


Fig. 2 Attempt to illustrate the mechanism of mechanical stress relief. If we assume a welded plate and pick four locations with residual stress magnitudes varying from 40,000 psi residual tension to 30,000 psi residual compression, their respective locations on the material stress-strain curve can be shown as points 1, 2, 3 and 4. If, for example, a tensile strain of 0.3% be applied, the points selected will move to 1', 2', 3' and 4'. On release of the applied elastic strain, the points chosen will drop to 1", 2", 3" and 4", having undergone varying amounts of plastic strain but arriving at a low residual stress. This is, of course, a very much idealized illustration. Multiaxial stress and variation in yield strength will result in less ideal stress relief. The tensile strain applied should be at least twice that necessary to cause yielding. Proof testing which is not ordinarily carried to or over the yield strength will still result in some measure of stress relief. In the case of a welded plate the yield strength of the deposited weld and heat-affected zone is usually higher than that of the plate stock. The release of elastic strain will take place from two or three yield strength levels and end up with a less ideal stress relief. The important fact remains that high tension residual stresses will be ironed out to a less harmful level

Fig. 3 Stress pattern for keyhole notch in flat bar subjected to central bending

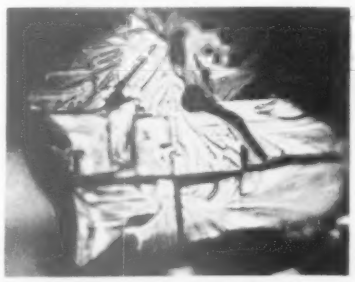


Fig. 4 Brittle cleavage fracture of mild steel showing low notch bar impact (3 ft-lb keyhole Charpy). X 1000 (Reduced by $\frac{1}{2}$ upon reproduction)

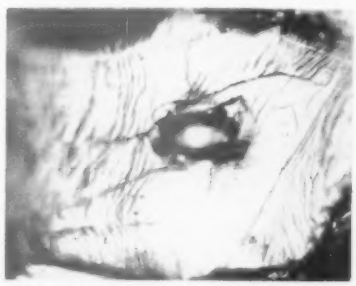


Fig. 5 Evidence of slip or glide on fracture surface of mild steel. This type of deformation absorbs much more energy than that shown in Fig. 4. This is not to be considered an example of ductile fracture. The fracture face merely illustrates the deformation which occurs in ductile fractures of ferritic steel. X 1000 (Reduced by $\frac{1}{2}$ upon reproduction)

Table 2—Effect of Subzero Temperatures on Charpy Keyhole Impact Toughness (Average) of Types 302 and 304 Stainless Steels

Alloy	C	Mn	Si	P	S	Cr	Ni	Testing temperature, ° F	Charpy impact toughness, ft-lb: Annealed at 2050° F and water quenched	Charpy impact toughness, ft-lb: Sensitized at 1000° F
302	0.11	1.08	0.29	0.012	0.012	18.43	8.90	Room	79.7	82.7
								−150	70.9	43.3
								−300	66.5	10.7
304	0.07	0.70	0.77	0.012	0.018	18.69	9.30	Room	75.6	81.1
								−150	82.4	78.7
								−300	79.7	60.0

and, since one of the principal stresses becomes zero at any edge, the stress at a boundary (edge) can simply be determined by multiplying the fringe number by the fringe constant of the model. In Fig. 3, a small area with high stress is surrounded by a large area with low stress. The net result is that, under further load, the small area finds difficulty in deforming plastically since it is restrained by the large surrounding area under low stress. Under these conditions, cracking may occur in a material which ordinarily has a high degree of ductility.

Stress relieving is carried out with the expectation that performance will be improved. The effects of stress relieving on the characteristics of low-alloy and carbon steels can broadly be classified as follows:

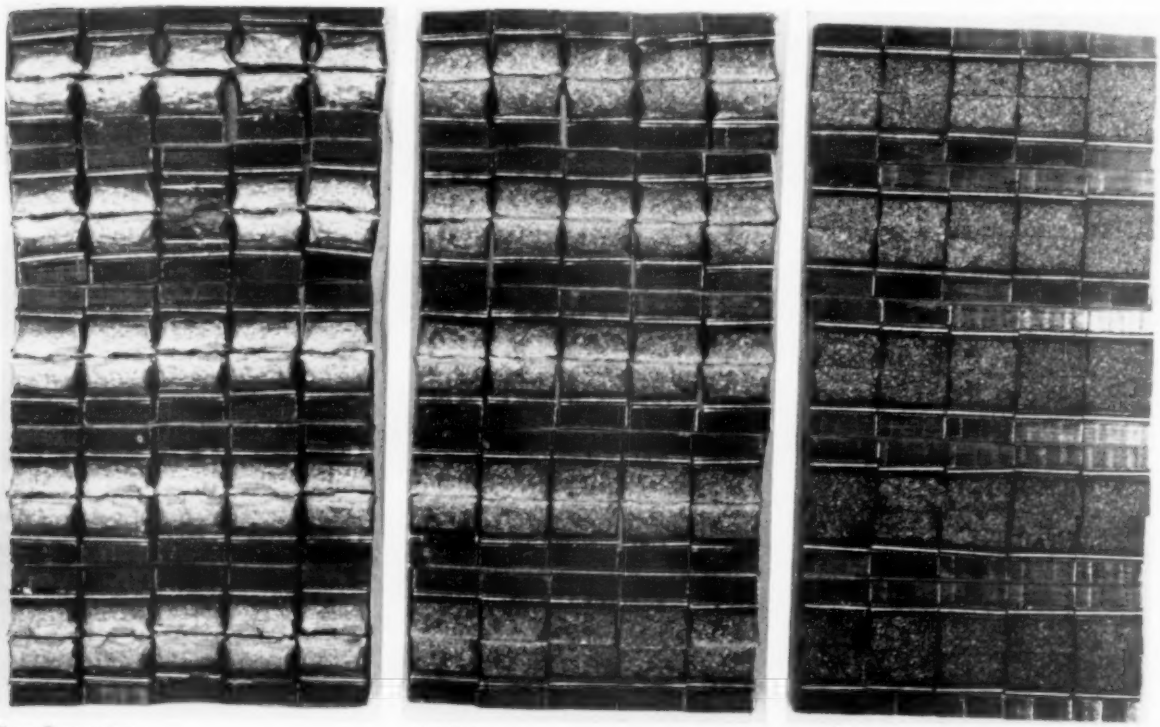
1. Structural changes. This included tempering of affected base metal and deposited metal. Structural changes are not all beneficial. For example, temper embrittlement can occur in some alloy steels at stress-relieving temperatures, or during slow cooling from the stress-relieving temperature. The structural changes which may occur in stainless steels at stress-relieving temperatures may have a more profound effect on performance than the relief of residual stress.

2. Mechanical changes. This includes relief of residual stress and diffusion of hydrogen from deposited metal or base metal. Residual stresses due to forming, heat treatment, casting or machining might also be included. In some cases, residual stresses (where stress gradients exist) can cause excessive distortion in machining operations. This can be extremely important where close machined tolerances are specified.

Generally, one may say that the need for stress relieving increases with carbon content, alloy content and thickness.

General Consideration of Stainless Steels

In considering stainless steels, the same general observations apply, but the picture becomes complicated by transformations which may occur at effective stress-relieving temperatures. Table 1 lists the commercial AISI and ACI stainless-steel types and compositions. The major classifications of stainless steels — martensitic, ferritic and austenitic — are



Room Temperature | −150° F. | −300° F.

Fig. 6 Type 302 annealed and sensitized at 1200° F after Charpy keyhole notch-bar test at low temperatures. Fracture at −300° F, has all the appearance of brittle cleavage failure. Figure 7 shows the intergranular fracture path

well known. We cannot expect that the picture, as regards stress relieving, will remain the same for these three stainless-steel groups.

Design, fabrication and heat treatment of much of our industrial equipment are largely governed by the various safety codes, the best known of which is the ASME Boiler and Pressure Vessel Code. Continuous interpretations, revisions and additions are carried on to maintain a three-way balance between industrial needs, experience and developments in research and engineering. In the case of equipment subject to severe corrosion, specific chemical compositions, heat-treatment procedures, fabrication requirements and supplementary tests may be required to assure that the equipment will be in its most favorable condition for the intended service.

The stainless steels are primarily used to resist corrosion, to avoid process contamination with iron, to facilitate cleaning of process equipment, to provide strength and scaling resistance at high temperatures and to provide impact resistance at low temperatures. Because of the wide variety of operating conditions to which the stainless steels are subjected, it is not possible to set up hard and fast stress-relieving procedures. Section VIII (UHA-32) of the ASME Code for Unfired Pressure Vessels states that all welded vessels constructed of ferritic or martensitic chromium stainless steels, except Type 405, shall be stress relieved in all thickness. Type 405 must be welded with electrodes producing an austenitic chromium—nickel weld deposit in this case. Exemption of Type 405 from mandatory stress relief will be considered in the section on ferritic stainless steels.

Section VIII also states "heat treatment, including stress relief, of welded vessels constructed of austenitic chromium—nickel stainless steels is neither required nor prohibited. The need for and details of heat treatment depend on the type of alloy steel and service conditions."

The austenitic stainless steels differ in several respects from the ferritic steels and some of these structural differences have a direct bearing on stress-relieving considerations.

One of the major disadvantages of all of the ferritic (body-centered cubic) steels is that they experience a transition from ductile to brittle behavior. Under certain conditions of stress, composition and metallurgical structure, this transition may lie above or below ordinary room temperature. In the ductile condition the steel will, when overloaded, deform by glide or slip and exhibit the ductility which is indicated by ordinary mechanical tests. In the brittle condition, the failure is by cleavage with little or no evidence of ductility. Figures 4 and 5 illustrate these two conditions. The concept of brittle fracture of ferritic steels is of importance here because residual stresses, in the presence of mechanical or metallurgical notches, may contribute to initiation and propagation of such fracture. In instances where material or service conditions are such that the possibility of brittle fracture exists, stress relief of ferritic steels is a safeguard. Face-centered cubic alloys such as austenitic steels, on the other hand, do not fail by cleavage and do not show the type of ductile-to-brittle transition experienced by ferritic steels. Extreme restraint as in very heavy welds or formation of non-ductile grain-boundary phases can result in fractures of austenitic steel which have a brittle appearance. Figures 6 and 7 illustrate this condition.

The austenitic steels may be in a metastable structural condition. For example, ambient temperature cold work will cause substantial percentages of ferrite to form in Types 301, 302 or 304. Castings and welds in these and other austenitic analyses contain appreciable ferrite.

Heating the austenitic stainless steels in the intermediate temperature range (800 to 1600° F) may cause a grain-boundary chromium-carbide precipitation.

Fig. 7 Intergranular fracture of annealed and sensitized Type 302 alloy Charpy-keyhole notch-impact specimen broken at −300° F. The fracture, shown in Fig. 6, has the appearance of cleavage. Actually it is intergranular caused by the brittle carbide grain-boundary network. Heuschkel[10] has shown that oxides, nitrides, carbides and silicates are grain-boundary weakeners in austenitic steel weld deposits. In spite of the brittle grain-boundary carbide, considerable deformation has occurred within the grains as shown by the slip lines. X 100 (Reduced by ⅔ upon reproduction)

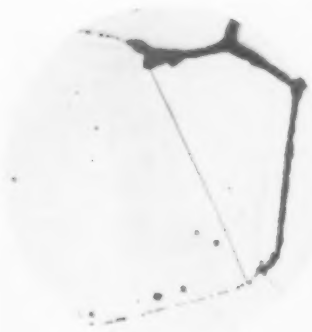


Fig. 8 Intergranular corrosion by HNO_3 in Type 304 alloy after heating to 1200° F for 1 hr. Small carbides at the grain boundaries provide the path for corrosion by lowering the chromium content around the grains. Diffusion of chromium to replenish the depleted zone can occur after long heating times at 1200° F or more rapidly at higher temperatures. Mahla and Nielson[12] showed very excellent electron microscope photographs of the leaf-like form of the carbide developed in heat treatment of Type 304. X 2000. (Reduced by ½ upon reproduction)

Fig. 9 Sigma phase formed in a modified Type 309 analysis (0.07%C, 23.90% Cr, 12.83% Ni, 1.18% Mo and 1.23% Cu) after extended heating at 1600° F. Austenite 247 Vickers. Sigma 1000 to 1100 Vickers. The agglomerated form is less detrimental to mechanical properties. X 1000. (Reduced by ½ upon reproduction)

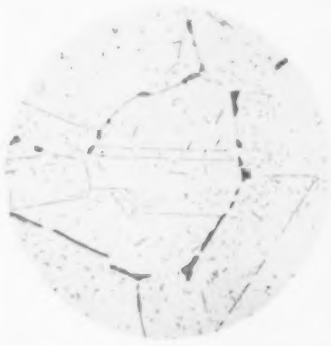


Fig. 10 Intergranular sigma phase formed in wrought Type 309 alloy after heating 600 hr at 1600° F. The continuous intergranular network severely limits ductility and notch impact strength. X 500. (Reduced by ½ upon reproduction)

Obviously the lower temperatures require extended heating times. This phenomenon lowers the corrosion resistance to many environments, as shown in Fig. 8, and also lowers the notch-bar impact strength, especially at low temperatures as shown in Table 2. Figure 7 shows the intergranular fracture resulting from the brittle grain-boundary chromium carbide. We note that the 0.08% maximum carbon Type 304 shows comparatively little sensitivity to this embrittlement. The stabilized grades containing columbium (niobium), columbium plus tantalum, titanium or the extra low-carbon grades are commonly used to prevent chromium-carbide precipitation and possible intergranular corrosion.

Heating the austenitic steels in the 1100 to 1700° F range in some cases can result in a slow transformation to the hard brittle sigma phase. When sigma or chromium carbide forms as a continuous grain-boundary phase, the notch-bar impact strength suffers. Generally the lower heating temperatures of the given ranges favor a continuous network and the higher temperatures tend to result in the coalescence of both carbide and sigma. The coalesced form is much less detrimental to mechanical properties. In alloys or weld deposits containing ferrite, sigma forms rapidly in the ferrite areas while it forms much more slowly in fully austenitic alloys. On the other hand, fully austenitic alloys tend to develop sigma at the grain boundaries which is more undesirable. Figures 9 and 10 illustrate the two types. So far as is known, sigma does not form in Types 301, 302, 304 and 308. Molybdenum, silicon, columbium and titanium will promote the formation of sigma phase in these alloys. Several intermetallic phases[5] in addition to sigma phase have been identified in the last few years. Chi, epsilon, eta and rho have been observed in alloys of iron, chromium, nickel, molybdenum, silicon and cobalt. They all form in the general range given for sigma and apparently have much the same effects. The possibility of embrittlement of stainless steels is recognized in Section VIII of the ASME Code for Unfired Pressure Vessels which states, in paragraph UHA-51, "Impact tests shall be made for the following combinations of materials and operating conditions.

(*a*) For all materials at operating temperatures below −325° F.

(*b*) For the following materials at operating temperatures below −20° F, except when the operating cycle is such that the pressure at −20° F is less than one-fifth of the maximum allowable working pressure at 100° F:

1. Ferritic chromium stainless steels.
2. Austenitic chromium-nickel stainless steels when carbon is in excess of 0.10%.
3. Austenitic chromium-nickel stainless steels that have a chromium or nickel content in excess of the AISI standard analysis range of the specified type number and physical form.
4. Material in casting form.
5. Material in the form of deposited weld metal.

(*c*) For the following materials at all values of operating temperature: Type 309, 316, 309Cb* or 316Cb (Type 318)* that is stress relieved at temperatures below 1650° F. These tests shall include the weld metal and shall be made at room temperature or at operating temperature, whichever is lower." Keyhole or "U" notch tests are required which, for the standard bar, shall have a minimum average value of 15 ft-lb for 3 bars and no one bar of the three may fall below 10 ft-lb.

* Type 309Cb and Type 318 are not standard AISI types but are commercially available.

Martensitic Stainless Steels

This classification derives its name from the austenite-to-martensite transformation which takes place when the steel is cooled from an austenitizing temperature. It comprises a group containing from about 12 to 14% chromium. By increased carbon, the chromium range can be extended to 18% (Type 440). With the addition of about 2% nickel, the martensitic transformation can be maintained to 17% chromium (Type 431).

Table 3—Effects of Heat Treatments on the Charpy-Keyhole Impact Properties of Various Weld Metals Tested at Room and Subzero Temperatures

Type of weld deposit	Heat treatment*	Ferrite, %	Impact toughness, ft-lb†		
			Room temperature	−105° F (−75° C)	−320° F (−196° C)
301	As-welded	—	36	21	5
	Annealed	—	11	30	24
302	As-welded	—	35	30	26
304	As-welded	—	34	26	20
	Annealed	—	44	40	35
308	As-welded	—	32	23	17
	Annealed	—	36	30	30
310	As-welded	—	36	30	24
	Annealed	—	32	28	19
316	As-welded	0.5	30	26	18
	Stress relieved		32	25	13
	Stabilized		28	21	13
	Annealed		34	29	22
316	As-welded	8.0	31	28	18
	Stress relieved		26	17	7
	Stabilized		11	7	3
	Annealed		37	33	25
317	As-welded	2.0	21	16	11
	Annealed		21	16	14
317	As-welded	5.5	11	7	4
	Annealed		11	6	3
318	As-welded	None	27	22	15
	Stress relieved		26	24	15
	Stabilized		21	15	13
	Annealed		31	26	20
318	As-welded	0.5	20	16	11
	Stress relieved		19	15	9
	Stabilized	None	9	7	5
	Annealed		25	20	15
347	As-welded	None	27	22	20
	Stress relieved		26	20	13
	Stabilized		22	15	14
	Annealed		25	25	18
347	As-welded	3.5	30	25	18
	Stress relieved		25	15	11
	Stabilized		20	16	14
	Annealed		26	25	24

* Heat treatments were as follows:
As-welded.
Stress relieved 2 hr at 1200° F (650° C)—AC.
Stabilized 2 hr at 1550° F (845° C)—AC.
Annealed ½ hr at 1950° F (1065° C)—WQ.

† Average of 2 to 6 tests.

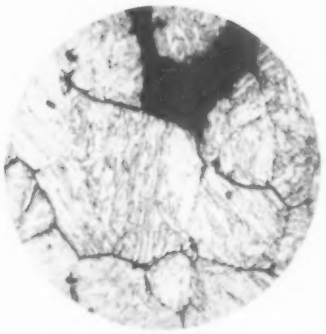


Fig. 11 Intergranular stress corrosion of Type 410 alloy exposed to acid atmosphere in a chemical plant. Hardness 27 Rc. X 500. (Reduced by 1/2 upon reproduction)

Because of the high-alloy content, hardening may take place at relatively slow cooling rates.

Stress relief of the martensitic stainless steels is desirable for both structural and mechanical reasons. Because of the high hardenability, preheat is maintained during welding, and stress relief should follow immediately. After welding and before stress relieving, the section should be permitted to cool to a temperature such that the martensite transformation is substantially complete. If this is not done, the transformation will take place on cooling from the stress-relieving temperature. Type 410 has an Ms (start of martensite transformation on cooling) at 675° F and the transformation is about 90% complete at 550° F.

General corrosion resistance is greatest in the fully martensitic state since this is the most homogeneous condition. However, the martensitic stainless steels are subject to stress-corrosion cracking in some environments, notably under acid conditions, where hydrogen sulfide or chloride ions are present on the steel surface, as shown in Fig. 11. Bloom[6] indicates that heat-treated Type 410 will crack at Rc 25 or higher in acetic acid and hydrogen sulfide, Rc 40 or higher will crack in marine atmosphere and Rc 45 or higher will crack in severe industrial and salt-fog atmospheres as well as in aqueous salt solutions. He also reports that stress relieving at 1100° F or higher will eliminate the cracking tendency.

The conventional annealing treatment for the martensitic grades consists of heating to 1350 to 1450° F and slow cooling to 1000° F. This is really a subcritical anneal as the ferrite-to-austenite transformation takes place above 1450° F. After tempering in the 800 to 1000° F range, some loss in notch-bar impact strength may be observed. Other properties such as tensile strength and elongation are not sensitive to this temperature range of stress relieving. Where stress relieving of the martensitic stainless steel is to be considered, the following points should be kept in mind.

(*a*) Greatest corrosion resistance and tensile strength will be found in the fully hardened condition.

(*b*) The fully hardened condition is susceptible to stress-corrosion cracking in some environments. A tempering temperature of 1100° F or higher will immunize the alloy to stress corrosion.

(*c*) A combination of good ductility and good corrosion resistance can be obtained by heating from 1350 to 1450° F, and slow cooling to 1000° F.

Ferritic Stainless Steels

The ferritic stainless steels undergo only partial or no allotropic transformation to austenite on heating. As a result, grain size can be controlled only by hot work or cold work and reheating. The transition from the martensitic to the ferritic type in commercial alloys does not take place at any one composition. For example, a low-carbon Type 410 will show some ferrite when rapidly cooled from the normal austenitizing temperature. Similarly, a 20% chromium alloy with 0.10% carbon will show some martensite when quenched from 1800° F. The ferritic grade is normally considered to begin at 14% chromium, but additions of carbon and nickel can promote austenite at higher chromium contents.

Stress relief of the ferritic stainless steels is necessary for both structural and mechanical reasons. Welding or heat treatment which results in a two-phase ferritic and martensitic structure has poor corrosion resistance in many applications. Stress relieving or annealing at 1450 to 1550° F will restore the original corrosion-resisting properties. The straight-chromium steels above 14% chromium are extremely notch sensitive and heat treatment to reduce residual stresses is helpful. Ductility is excellent in the absence of sharp stress raisers and these alloys are commonly spun and cold formed to a variety of shapes.

Type 405 is a rather special case. It has the same composition as the martensitic Type 410 except that the addition of about 0.20% aluminum suppresses the austenite formation to about the same level as the higher chromium alloys, with the result that Type 405 has a low hardenability and about the same impact transition[7] as the Type 410. For these reasons it is specifically exempted from mandatory stress relief by Section VIII of the ASME Code when welded with austenitic electrodes. When stress relief is omitted, it is necessary to prepare welded test plates representing each Type 405 heat used and subject these plates to face-bend tests.

The straight-chromium stainless steels above 14% chromium are subject to a pronounced embrittlement when heated in the 750 to 900° F range. This has long been known as the "885° F embrittlement." The higher chromium types such as Type 446 may embrittle merely on slow cooling through this temperature range. On the other hand, with chromium less than 14% it requires months of heating to embrittle appreciably. Below 12 to 13% chromium, the annealed alloy will not embrittle. Figures 12 and 13 show the results of long heating at 885° F on a Type 446 alloy.

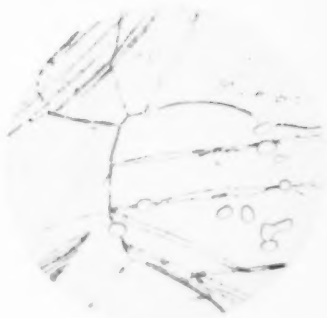


Fig. 12 Type 446 alloy showing precipitation at grain boundaries and at mechanical twins after heating at 850° F. X 2500. (Reduced by 1/2 upon reproduction)

A high-temperature embrittlement of the ferritic stainless steels has also been described.[8] It is associated with a coarse ferrite grain size due to heating at temperatures over 2100° F.

A third form of embrittlement in the straight-chromium steels results from a slow polymorphic transformation to hard brittle sigma phase when heated in the 1025 to 1300° F range. It is of practical importance only in the highest chromium types. Transformation is very slow, unless the alloy has been cold worked when it occurs more readily. At the normal annealing temperature of 1500° F minimum, sigma will transform

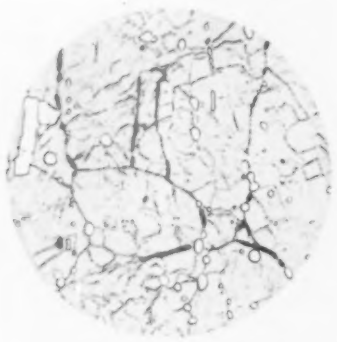


Fig. 13 Same as Fig. 12 etched longer to show precipitation and substructure within the grains. Hardness increased from 87 RB to 39 Rc after heating for 16 months at 850° F. X 2500. (Reduced by 1/2 upon reproduction)

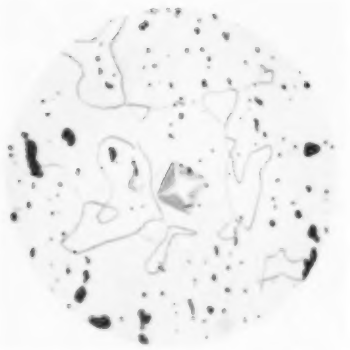


Fig. 14 Sigma phase formed in an alloy of 0.06% C and 28.24% Cr after heating for 8 months at 1250° F. Etched with Murakami's reagent which darkens carbides. Microhardness taken with Eberbach hardness tester, 30.5-g load. Ferrite 184 to 196 Vickers. Sigma 1000 to 1150 Vickers. In the annealed condition, sigma forms in colonies in this wrought alloy and only about 5% was present even after the long heating period. When cold worked, transformation is much more rapid. Etched with aqua regia, this type of sigma darkens very rapidly, as seen in Fig. 15. X 1000. (Reduced by ½ upon reproduction)

to ferrite in the straight chromium alloys. Figures 14 and 15 illustrate sigma phase in Type 446.

In stress relieving any of the ferritic stainless steels, we should keep these points in mind:

(*a*) Best mechanical properties and best corrosion resistance will be obtained by annealing steels with the lower chromium range at 1350 to 1450° F, and those in the higher chromium range at 1450 to 1550° F. Air cooling is desirable.

(*b*) The ferritic chromium stainless steels develop a coarse crystalline structure at welding temperatures. In the presence of metallurgical or mechanical notches, the ambient-temperature ductility may be very low. At temperatures above 400 to 500° F the ductility is good.

(*c*) There are three temperature ranges which should be avoided when heat treating the straight-chromium ferritic stainless steels. The heating range (750 to 900° F) will embrittle the higher chromium steels for subsequent room-temperature service. The rate of embrittlement depends on the chromium content. In the 1025 to 1300° F range, a slow transformation to brittle sigma phase will occur in steels containing over 20% chromium. Prior cold work and high chromium accelerate this transformation. A high-temperature embrittlement associated with a coarse-ferrite grain size and carbide solution can result from heating at temperatures over 2100° F. Annealing in the temperature range suggested will restore the original properties except that some loss in mechanical qualities will persist after the high-temperature embrittlement due to the coarse grain size.

Austenitic Stainless Steels

In order to make intelligent decisions as to the need for stress relief when considering austenitic stainless steel for a specific application, it is necessary to recognize the characteristics of these steels.

(*a*) The austenitic stainless steels are not notch sensitive. Except when dealing with extreme thicknesses or when a grain-boundary weakness is present, brittle fracture will not occur. Stress relief is of no benefit if carried out to increase notch toughness, and may actually decrease notch-impact strength if it is carried out in a range where brittle grain-boundary phases such as carbide or sigma may form. In welding heavy sections, the buildup of multiaxial stresses may require stress relief, for these stress systems severely limit ductility.

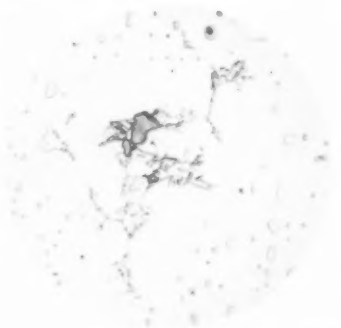


Fig. 15 Sigma phase partially transformed back to ferrite and carbide. Same alloy as shown in Fig. 14 after heating to 1550° F, 4 hr. Slightly higher temperature would have completed the transformation. Dark etching areas are sigma phase. Light etching areas are carbide. X 1000. (Reduced by ½ upon reproduction)

(*b*) Under certain specific conditions of stress, environment and temperature, the austenitic stainless steels are subject to stress corrosion (Fig. 16). Generally, residual stresses are more dangerous than design stresses in promoting stress corrosion, because they are usually higher and more localized. For this reason, stress relief may be necessary. Stress-corrosion cracking is caused by tension stress. Any treatment which results in compression stress on the exposed surface is helpful in the control of stress-corrosion cracking. Control of environment, reduction of temperature or removal of residual stresses, providing design stresses are low, can reduce or eliminate stress corrosion. However, if stress corrosion is a severe problem, it is safer and more practical to select an alloy resistant to stress corrosion in the particular application in question. This might include a more highly alloyed material or, in some cases, one of the straight-chromium types. Any condition which encourages concentration of salts may initiate pitting and can rapidly promote stress corrosion even though a low stress level exists. Conditions which favor concentration of salts include crevices, notches, scale and insoluble deposits on the surface.

(*c*) In order to control interdendritic fissuring of austenitic weld deposits, it is common practice to balance the alloying elements of Types 304, 308, 309, 316, 347 and 348 in order to obtain about 5% ferrite in the deposit.[9] The Schaeffler diagram is often used by welding engineers to estimate the structure resulting from a specific composition. This dispersed ferrite acts to break up the continuous dendritic grain boundaries which may be weak at certain temperatures when cooling. Heuschkel[10] has shown that oxides, carbides, nitrides and silicates act to weaken the austenite grain boundaries of weld deposits. If austenitic deposits are stress relieved in the signatizing temperature range, the ferrite areas in Types 309, 316, 317, 321, 347 and 348 will transform to sigma phase. In extremely critical installations it is advisable to anneal these sections at a temperature which will convert the ferrite to austenite rather than sigma. Table 3 shows the results of notch-bar tests on austenitic deposits after various heat treatments. Figure 17

Fig. 16 Transgranular stress-corrosion cracking of Type 304 inlet nozzle liner ¼-in. thick x 5⅛-in. OD handling 300° F sulfate paper mill liquor. Forming and welding stresses caused rapid cracking. Replacement nozzle was annealed at 1950° F and performed satisfactorily

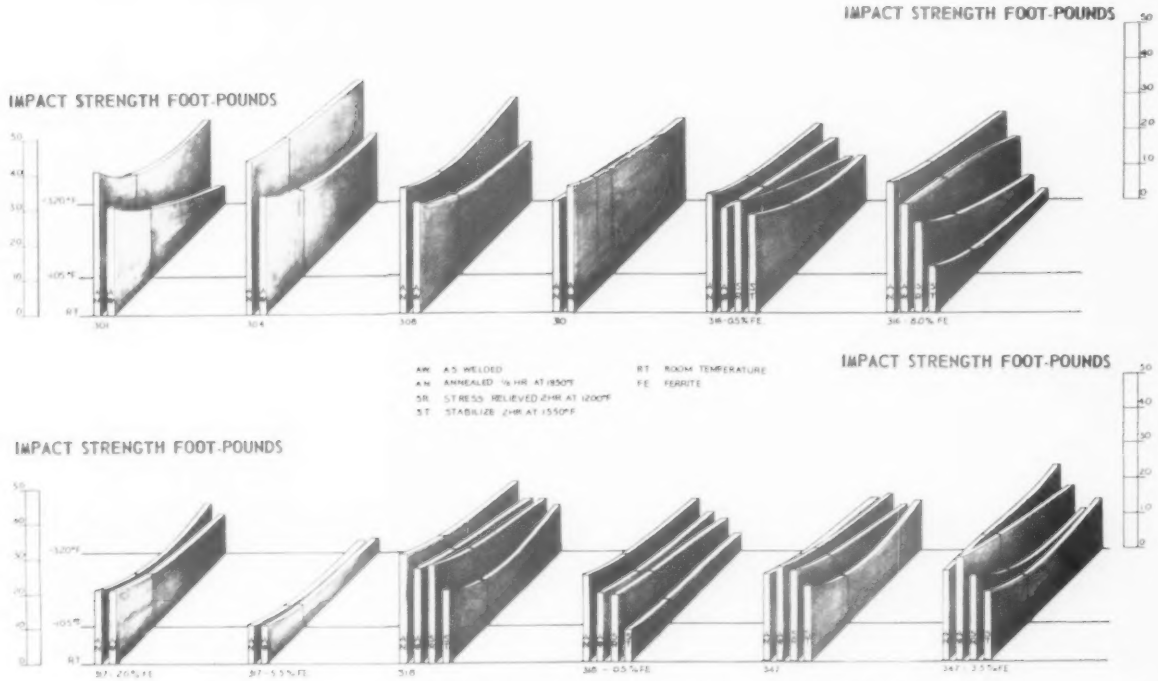


Fig. 17 The effect of heat treatment on the Charpy-keyhole impact strength of deposited weld metal

shows the same data in a three-dimensional view.

(d) Based on the effect on the austenitic stainless steels, heat treatment can be broadly divided into three ranges. Depending on the conditions involved, any one of the three ranges may be required for stress relieving.

1. 800 to 1600° F. This is commonly called the sensitizing range since the non-stabilized austenitic grades will undergo carbide precipitation with the consequent reduction in corrosion resistance to some media. When it is necessary to heat in this range, the extra-low-carbon grades 304 L and 316 L have definite advantages for they will not sensitize in the heating times involved in normal shop fabrication. They will become sensitive to intergranular corrosion after extended heating periods in the 1000 to 1100° F range. The response of deposited weld metal to heat treatment in the sensitizing range and in the stabilizing may not follow that of a like wrought analysis. The corrosion behavior of deposited weld and stock may differ widely after identical heat treatment.

2. 1350 to 1750° F. This is generally known as the stabilizing range since it is possible to precipitate carbides in less harmful form with the proper selection of time and temperature. Depending on the alloy and time of heating, stabilization can occur on heating below 1350° F. The hazards of heat treatment in this range should be recognized. Some embrittlement due to sigma formation may occur in any of the grades other than 301, 302, 304 or 308. At the lower temperatures, sensitization will occur unless the alloy is stabilized with columbium or titanium or is one of the extra-low-carbon grades, and even these grades suffer some loss in corrosion resistance.

3. 1750 to 2050° F. This is the annealing range for the austenitic steels. When the annealing treatment is specified it is necessary to cool Types 301, 302, 303, 304, 308, 309, 310, 316 and 317 rapidly if maximum corrosion resistance is desired. It has been suggested that cooling between 1700 and 1000° F be accomplished in no more than 3 min in order to prevent precipitation of chromium carbides. In large structures rapid cooling must be prescribed with care since high residual tension stresses and even distortion may result. Distortion of assemblies can occur at the higher annealing temperatures, and adequate support must be provided. If carbon content in these steels exceeds 0.10% when thickness is greater than 0.078 in., or if alloy content is high as in Types 309 and 310, water quenching of sheet and plate is recommended to minimize carbide precipitation. Water quenching may also be advisable to prevent sigma formation during cooling of heavy gage Type 317 sheets and plates.

The effect of stress-relieving temperature on the time for transgranular stress-corrosion cracking to occur is shown in Table 4.[13] These tests were made on thin gage cold drawn Type 347 and Type 316 tubing. The finishing operations were such as to leave a high residual circumferential stress in the Type 316 tube and high longitudinal residual stress in the Type 347 tube. Typical cracking is shown in Fig. 18. It is interesting to note that 1375° F was quite effective in removing residual stress from the Type 347 material while Type 316 retained sufficient residual stress to cause rapid cracking after stress relieving at 1450° F. Heavy sections and especially heavy welds would require higher temperatures for the same degree of stress relief. In general, this observation is borne out by the greater creep resistance of the Type 316 steel as compared to Type 347. Creep strength, however, is not an accurate measure of an effective stress-relief

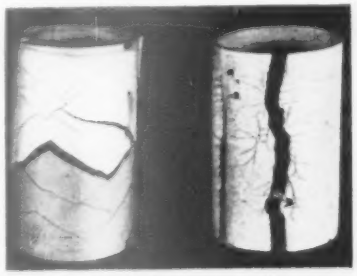


Fig. 18 Typical transgranular stress-corrosion cracking produced in cold-drawn stainless-steel tubing after testing in 42% magnesium-chloride solution at 309° F. Type 347 tube on left contained high longitudinal residual stress while the Type 316 tube on the right contained high residual circumferential stress. Cracking shown took place in 7½ hr test of the as-drawn tube sections. X3. (Reduced by ½ upon reproduction)

Table 4– Effect of Stress-Relieving Temperature on Stress-Corrosion Cracking in Boiling Magnesium-Chloride Solution at 309° F

No.	Type	Heat treatment			Measured residual stress: Circumferential, psi	Measured residual stress: Longitudinal, psi	Time to crack, hr
1	347	Full hard—no heat treatment			46,200	69,000	7½
2	347	1000° F	24 hr	Air cool			7½
3	347	1200° F	½ hr	Air cool			22
4	347	1200° F	8 hr	Air cool			14½
5	347	1375° F	½ hr	Air cool	1,850	8,450	245—one small crack
6	347	1375° F	½ hr	Furnace cool			292—one small crack
7	347	1600° F	½ hr	Air cool			292—no cracks
8	347	1600° F	½ hr	Furnace cool			292—no cracks
9	347	1600° F	24 hr	Air cool			292—no cracks
1	316	Quarter hard—no heat treatment			52,500	20,200	7½
2	316	1000° F	24 hr	Air cool	44,500		7½
3	316	1200° F	½ hr	Air cool	39,100		7½
4	316	1200° F	8 hr	Air cool			14½
5	316	1375° F	½ hr	Air cool	26,700		22
6	316	1375° F	½ hr	Furnace cool	23,100		22
7	316	1375° F	8 hr	Air cool			22
8	316	1450° F	½ hr	Air cool	10,400		24
9	316	1550° F	½ hr	Air cool	3,600		240—no cracks
10	316	1600° F	½ hr	Air cool	3,500	8,300	292—no cracks
11	316	1600° F	½ hr	Furnace cool			292—no cracks
12	316	1600° F	24 hr	Air cool			292—no cracks

Tested in 42% magnesium chloride at 309° F

Tests were made on 0.035-in. wall x ⅝-in. OD welded and cold drawn tubing of the following analysis:

	C	Mn	Si	Cr	Ni	Cb	Mo
Type 347	0.05	1.50		18.86	10.74	0.88	0.08
Type 316	0.05	1.42	0.48	17.62	10.55		2.76

Residual stress was measured by the slitting techniques

ing temperature, for creep tests are carried out under constant load and stress relief occurs by relaxation. Table 5[11] shows the relaxation of stress in Type 304 stainless steel after 100-hr heating at various temperatures.

Table 5—Short Time (100 hr) Relaxation Data for Type 304

Heating temperature, °F	Initial stress, psi	Stress after heating, psi
1000	30,000	12,750
1000	30,000	8,200
1200	25,000	6,200
1250	25,000	6,300

A number of general cautionary notes are useful:

Type 347 may develop intergranular cracking when stress relieving a highly stressed structure. This appears to be a stress-rupture type of failure where cracking occurs before the residual stresses are relaxed.

Corrosion during heat treatment can occur in oil-fired furnaces at solution-treating temperatures.

Molybdenum-containing alloys such as Types 316 and 317 may oxidize rapidly during heat treatment, particularly when stagnant-atmosphere areas exist at the metal surface.

Carburization of metal surface can result from grease or oil which is not removed.

Paints and marking compounds containing lead, zinc or sulfur can cause corrosion or penetration during heat treatment.

In cracked ammonia atmospheres some nitriding of the surface can occur.

The presence of welding slags may produce corrosion during the heat-treating cycle.

From what has been said, it is evidently advisable to stress relieve austenitic stainless steels only under the following conditions:

1. When service environment is conducive to stress corrosion.
2. When dimensional stability is required. This may include dimensional stability in machining operations or during subsequent service when nonuniform stress relaxation might occur.
3. In some cases, life under cyclic loading may be diminished by high residual stresses. This is a minor consideration with the austenitic grades.
4. In extremely heavy sections, welding may impose a multiaxial-stress system which severely limits ductility. Stress relief is one way of correcting this condition. Precautions regarding stress relief of highly-stressed Type 347 must be taken.

Thermal treatments for other reasons than stress relief may be desirable due to the metallurgical characteristics of these steels.

No hard and fast set of rules can be set up to cover stress relieving of austenitic stainless steels. A knowledge of their characteristics and the exercise of careful judgment are the only suggestions which can be made. In all cases the service requirements govern. Evaluation of these service requirements coupled with careful consideration of the basic steel characteristics dictate the type of heat treatment, if any, which the engineer must specify.

Acknowledgment

The author wishes to express his appreciation for the assistance of T. N. Armstrong who acted as coordinator on behalf of the Pressure Vessel Research Committee. The many constructive suggestions of the reviewers are also deeply appreciated. Figure 17 was suggested and sketched out by Dr. Foley.

The encouragement and help of M. A. Scheil and J. J. Chyle and other colleagues of the Research Division of the A. O. Smith Corp. are also gratefully acknowledged.

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IMPROVING THE FATIGUE LIFE OF SPOT WELDS

Some explanations on increasing fatigue life through stress distribution in hydrodynamically compressed spot welds

The Need for Research

Resistance welding has already proved its inherent advantages as an assembly process. However, the potential is still great for improving its quality and production capability, as well as lowering its cost factors.

In many cases that potential for improving resistance-welding techniques is greater than such potential exists for improving other manufacturing processes.

The potential for improvement is understandable in view of (1) the number of variables involved, and (2) the exceedingly large combination of those variables that will produce satisfactory results.

A Project for Research

Although the fatigue life of spot welds subjected to cyclic loads compares favorably with rivets, improvement is desirable to keep pace with the advancing requirements of jet aircraft, high thrust jet engines, guided missiles, unitized body-frame for automobiles, etc.

The endurance limit of spot welds under repeated loading is approximately 12% of their shear strength regardless of the material used.

For the past eight years hydrostatic and hydrodynamic compression procedures have produced an increase of 400% in fatigue resistance. The criteria were loads applied for a duration of 10 millions of cycles.

Present research concerns the "hows and whys" of this startling increase in fatigue life. Consideration is being given the variations in (1) the compressed area around the spot weld, (2) the amounts of compression, (3) the shape of the tips used, (4) the evaluation of residual stress magnitude and distribution "as welded," and (5) the evaluation of residual stress magnitude and distribution following hydrostatic and hydrodynamic treatment.

Indications are that decidedly more favorable stress distribution results when the spot weld is somewhat prestressed compressively and must revert to zero stress before actual tensile stresses can develop.

However, such large hydrostatic compressive stresses are difficult to apply commercially.

Thus, the Council is devoting its attention to a study of the reasons underlying such fatigue life improvement. The objective is to determine other methods more commercially feasible to produce such improvement.

Preliminary investigation indicates the dynamic forces of 30- or 40-lb drop hammer will produce comparable result. Such a drop hammer could feasibly be incorporated in the welding cycle.

Notes on Diagrams

Figures 1 through 8 portray schematically what is believed to occur to a hydrostatically or hydrodynamically prestressed spot-weld specimen.

It is indicated that an important part of the total external load will be absorbed by the negatively directed stresses. As a result, the external load stresses start far below the zero load.

Thus, considerable fatigue life is gained before the external load becomes positive stresses.

The governing factor in fatigue resistance improvement appears to be attainment of the most advantageous ar-

Fig. 1 Stress distribution in a single plate under tensile load

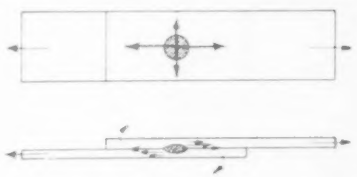

Fig. 2 Stress distribution in a spot weld under tensile load

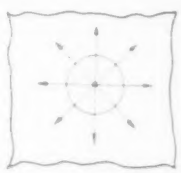

Fig. 3 Residual stress in a spot weld "as received"

(*Continued on page 336-s*)

A program in basic research by Welding Research Council, 29 West 39th St., New York 18, N. Y.

ROLE OF PHOSPHORUS IN AUSTENITIC MANGANESE WELD METAL

Phosphorus content of austenitic manganese weld metal found to be a more potent factor in alloy balance than generally recognized previously

BY W. T. DELONG, W. L. LUTES AND H. F. REID, JR.

INTRODUCTION. In an earlier comparative study,[1] mechanical properties of weld metal deposited by one composite nickel-manganese electrode proved radically different from those of four other nickel-manganese or molybdenum-manganese deposits under study. The five types of commercial austenitic manganese electrodes represented different approaches to the welding problem and, presumably, should be expected to produce approximately the same end results. Cause of the marked variation in results reported could not be explained from the initial data.

Analysis of the weld deposits, Table 1, showed variations in alloy balance of the major alloying materials which probably contributed somewhat to the normal scatter of data. At the same time, these variations did not appear great enough to explain fully the dramatic changes in tensile strength, elongation, impact strength and crack resistance of the weld deposit that were encountered.

Phosphorus content of the outstanding weld deposit, Composition 1A, was less than half that of the other austenitic manganese alloys tested. An investigative program was started, therefore, to determine if this seemingly distinctive feature of alloy balance accounted for the observed improvement in properties of the weld deposit.

Welding literature contains only limited references to the role of phosphorus in austenitic manganese steel or austenitic manganese weld metal. Standard references[2,3] suggest that phosphorus contents below 0.10% are harmless. This level of acceptability is based on room-temperature mechanical properties and reportedly is reduced to 0.06% maximum for applications involving hot strength and ductility. Many current mill specifications for wrought austenitic manganese electrodes core wire restrict phosphorus contents to a maximum of 0.07%.[4] This phosphorus level also has been adopted as the maximum permitted in austenitic manganese weld metals.[5]

A few years ago, a European investigator[6] reported that welding characteristics of austenitic manganese plates and castings were improved by reducing the phosphorus content of the base metal.

W. T. DeLong, W. L. Lutes and H. F. Reid, Jr., are associated with The McKay Co., York, Pa.

Alternate paper for 1958 AWS National Spring Meeting held in St. Louis, Mo., Apr. 14-18.

Experimental Work

Experimental work was concentrated on determining the properties of weld metal deposited by a series of experimental nickel-manganese electrodes. Alloy balance of each of these experimental weld metals was approximately similar to that of Composition 1A except that phosphorus level was varied between 0.01 and 0.06%. Armco iron core wire was used in the preparation of experimental electrodes where weld metal with minimum phosphorus content was desired. On all other electrodes, conventional mild-steel core wire was employed. Minus 100 mesh ferrophosphorus was added to the coating of experimental electrodes to produce weld metals with successively higher phosphorus contents.

A commercial electrode employing a nickel-manganese core wire was simulated in the laboratory using low phosphorus, alloy-enriched coating and mild-steel core wire. Properties of the resultant weld metals were compared.

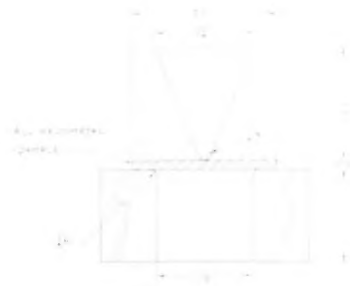

Fig. 1 All-weld-metal bend-test specimens

A limited amount of exploratory work was conducted along similar lines using molybdenum-manganese electrodes. This phase of the study was designed merely to determine if the general response of molybdenum-manganese alloys paralleled that of nickel-manganese materials.

Preparation of Test Specimens

All tests were made using welded or all-weld-metal test specimens prepared in the same manner as outlined in the earlier work.[1] Tests for the nickel-manganese alloys included conventional methods for measuring ultimate tensile strength, ductility and impact strength.

Table 1—Composition of Commercial Austenitic Manganese Weld Metals

Composition No.	*General type*	*Analysis of weld-metal deposit, %*						
		Carbon	*Chromium*	*Manganese*	*Molybdenum*	*Nickel*	*Phosphorus*	*Silicon*
1A	Composite nickel-manganese	0.75	0.38	14.5		3.46	0.021	0.65
1B	Nickel-manganese (alloy wire)	0.60	0.38	12.5		3.55	0.049	0.70
1C	Nickel-manganese (tubular wire)	0.58	0.41	11.6		3.24	0.053	0.43
2A	Molybdenum-manganese (alloy wire)	0.41	0.11	12.3	1.02		0.049	0.71
2B	Molybdenum-manganese (tubular type)	0.36	0.12	11.9	1.12		0.055	0.35

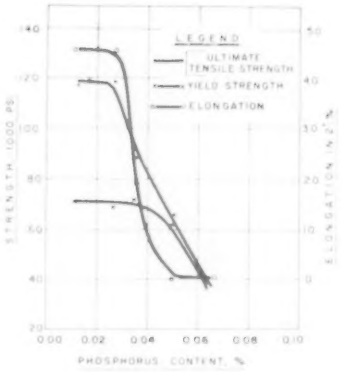

Fig. 2 Effect of variations in phosphorus content on mechanical properties of nickel-manganese weld metals containing about 15% manganese

A special test was used to evaluate the general susceptibility of individual alloy to cracking. An all-weld-metal bend-test specimen was also used in the exploratory study of molybdenum-manganese alloys.

The all-weld-metal bend test employed specimens approximately $\frac{1}{2}$ x 3 x $\frac{3}{16}$ in. cut from pads of undiluted weld metal normally used as the source of material for chemical analysis. Top and bottom surfaces were rough machined approximately parallel. Load was applied at the mid-point of the specimen, Fig. 1, until fracture occurred. Previous laboratory experience formed a basis for the following conversion scale:

Angle of bending, deg	*Approximate elongation in 2 in., %*
120 and over	36-45
106-119	28-35
90-105	20-27
60-89	15-19
30-59	9-14
15-29	4-8
0-14	0-4

Effect of Phosphorus on Nickel-Manganese Weld Metal Containing 14.8% Manganese

As indicated earlier, work was concentrated on a study of the effects of variations in phosphorus content on properties of otherwise essentially similar nickel-manganese weld metals. The base alloy for the major phase of the investigation contained about 0.7% carbon, 14.8% manganese and 3.6% nickel. Phosphorus contents were investigated in the range of 0.01 to 0.06% as shown in Table 2.

Mechanical Properties

Tensile strength and ductility of the experimental nickel-manganese alloys were altered markedly by variations in phosphorous content of the weld deposit, Fig. 2. Effect on yield strength was less pronounced with reductions occurring only after test specimens began to exhibit cracking tendencies.

Tensile strength, yield strength and elongation decreased sharply.

These distinctly poorer results should not be interpreted as indicating that commercially satisfactory nickel-manganese alloy combinations for surfacing applications cannot be produced at these phosphorus levels. A number of such alloys is being used successfully.

Table 2—Composition of Experimental Nickel-Manganese Weld Metals

Composition No.	*Analysis of Weld Deposit, %**					
	Carbon	*Chromium*	*Manganese*	*Nickel*	*Phosphorus*	*Silicon*
1A†	0.75	0.38	14.5	3.46	0.024	0.65
1A-1	0.71	0.39	15.1	3.64	0.013	0.57
1A-2	0.61				0.027	
1A-3	0.64	0.36	14.5	3.57	0.035	0.53
1A-4	0.65				0.050	
1A-5	0.68		14.8		0.063	
1B†	0.60	0.38	12.5	3.55	0.049	0.70
1B-1	0.51	0.27	12.4	3.29	0.013	0.61

* Values not shown were assumed to be in the nominal range of others of the series.
† Repeated from previous work for comparison purposes.

Tensile strengths of the deposits consistently were in excess of 100,000 psi when phosphorus content was 0.025% or less. These high strengths were accompanied by elongation values in the range of 40-50%. Fractured tensile specimens exhibited a tough fibrous structure resembling somewhat that of a properly balanced Type 310 weld metal.

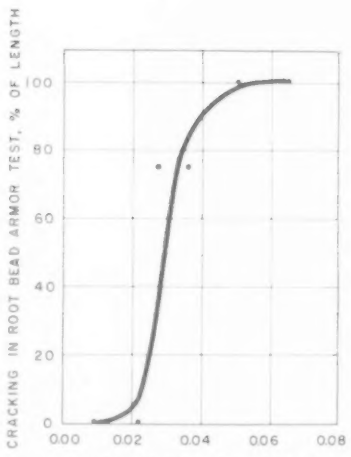

Fig. 3 Crack resistance of high-manganese nickel-manganese weld metals

In alloys containing 0.026 to 0.03% of phosphorus, small variations in phosphorus content affected sharp changes in the appearance of fractured specimens and properties of the resultant deposits. At the lower side of the range, weld deposits were strong and ductile. As phosphorus content increased, strength and ductility began to fall off. The fibrous appearance of fractured low-phosphorus alloys was replaced by a somewhat more crystalline cross section.

Further increases in phosphorus content over 0.035% resulted in weld metals with definite "hot-short" characteristics.

Crack Resistance

The effect of phosphorus content on resistance of the alloys to root-bead cracking in the armor-weld-crack test paralleled results of tensile tests, Fig. 3.

Low-phosphorus, nickel-manganese weld metal had crack resistance equal to that of armor-welding materials. Crack sensitivity increased sharply as phosphorus content of the alloy was increased above about 0.035%.

It is acknowledged that the test procedure used to rate these alloys was extremely severe. Failure in this root-bead crack test does not, in itself, imply that a material is unacceptable for commercial application. Many accepted weld metals such as Types 308 or 309 stainless steel also fail this test.

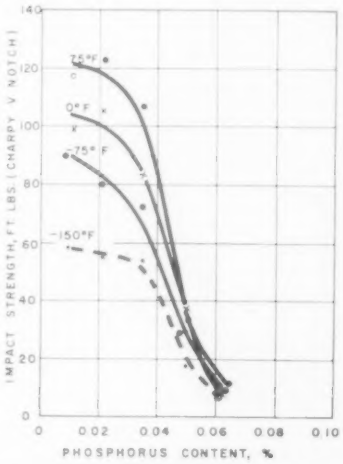

Fig. 4 Impact resistance of high-manganese nickel-manganese weld metals

Table 3—Composition of Experimental Molybdenum-Manganese Weld Metals

Composition No.	Analysis of weld metal, %* Carbon	Manganese	Phosphorus	Silicon	Molybdenum
2C-1	0.80	14.5	0.014	0.66	1.00
2C-2			0.019		
2C-3			0.022		
2C-4	0.75	14.5	0.028	0.68	0.96
2C-5			0.036		
2C-6			0.043		
2C-7			0.047		
2C-8	0.80	14.6	0.050	0.65	0.94
2A†	0.41	12.3	0.049	0.71	1.02
2A-1	0.46	13.0	0.013	0.65	1.17

* Repeated from previous work for comparative purposes.
† Values not shown were assumed to be in the nominal range of this series.

Impact Strength

Impact strength of the experimental nickel-manganese alloys was related directly to phosphorus level, Fig. 4. At all temperature levels investigated, impact strengths (Charpy V-notch) of the lower phosphorus alloys were superior to those of materials containing amounts of phosphorus previously considered as commercially acceptable. Generally speaking, zero and subzero impact strengths of the low-phosphorus alloys exceeded room-temperature impact strength of their higher phosphorus content counterparts.

Effect of Phosphorus on Nickel-Manganese Weld Metals Containing About 12% Manganese

The range of manganese contents of acceptable nickel-manganese materials is extremely broad. The previous section summarized the results made using high-manganese nickel-manganese materials. A limited number of tests also was made using low-manganese materials similar to those found very frequently in commercial use. The results of these tests are summarized graphically in Figs. 5 and 6.

Weld-metal properties of 12% manganese alloys also were influenced markedly by variations in phosphorus content. Tensile strength of the low-phosphorus alloy was approximately 200% that of the higher phosphorus counterpart. Elongation of the low-phosphorus weld metal was more than 300% that of the higher phosphorus material. The higher phosphorus alloy was crack sensitive whereas the low-phosphorus counterpart repeatedly exhibited exceptional crack resistance in the root-bead crack test.

Impact strengths of 12% manganese nickel-manganese weld metal were also improved by reduction in phosphorus content of the deposit. At room temperature, the change was not significant. At zero and subzero temperatures, however, impact strengths of low-phosphorus test specimens consistently were 50 to 75% higher than those of the higher phosphorus materials.

It was of interest that, although the pattern of improvement with reduced phosphorus content was similar for both the 12 and 14% nickel-manganese alloys, the actual level of impact values varied appreciably.

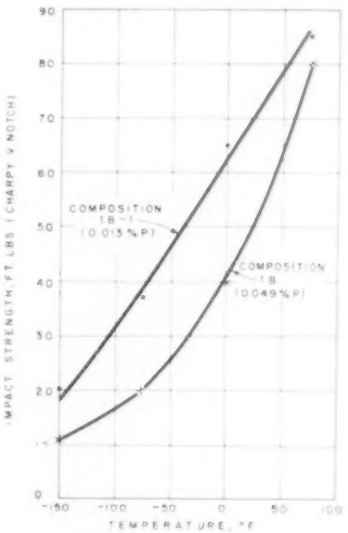

Fig. 6 Impact strength of two approximately 12% manganese alloys

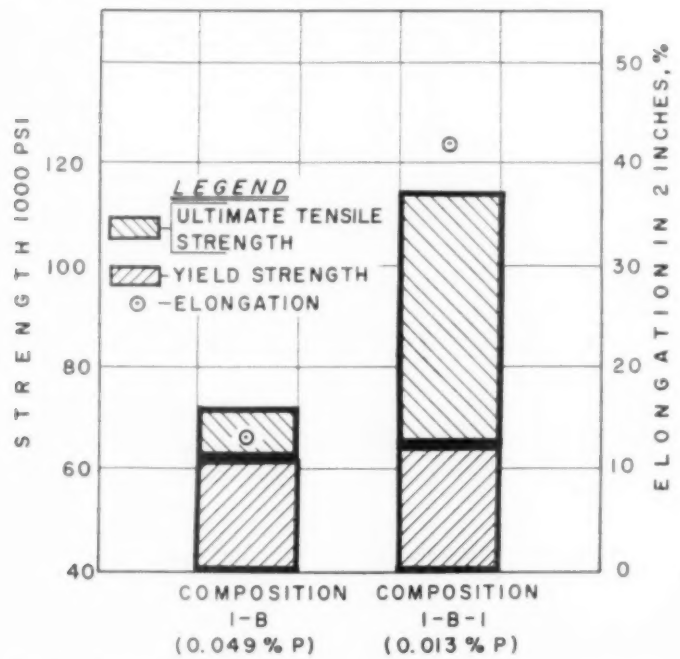

Fig. 5 Comparative mechanical properties for two nickel-manganese alloys containing about 12% manganese

The higher manganese, low-phosphorus alloys had better impact strengths over the entire temperature range investigated. This significant fact further emphasizes that specific alloy balance of major constituents cannot be overlooked if the ultimate alloy is to have the optimum combination of properties.

The difference was probably due to the austenite stability of the two alloys. The austenite of the higher carbon, higher manganese alloy should be the more stable under conditions of cold working or low temperature. Both austenites, however, were reasonably stable at room temperature as judged by the lack of any measurable transformation to martensite in the tensile test. They remained completely nonmagnetic even after 40 and 45% elongation.

Exploratory Molybdenum-Manganese Study

A limited number of tests was made using molybdenum-manganese alloys to

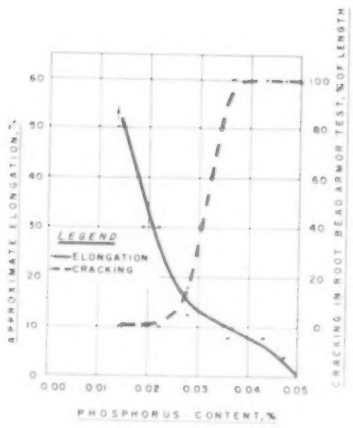

Fig. 7 Effect of variations in phosphorus content on ductility and crack resistance of molybdenum-manganese alloys containing about 14% manganese

determine if the marked influence of phosphorus content on properties of nickel-manganese alloy was duplicated in molybdenum-modified austenitic manganese alloys. Compositions of these experimental weld metals are summarized in Table 3.

Molybdenum-Manganese Alloys Containing 14% Manganese

Base alloys for these exploratory tests contained about 0.8% carbon, 14.5% manganese and 1% molybdenum. Phosphorus content of experimental weld metals was varied from approximately 0.01 to 0.05%. Effects of these variations on ductility and crack resistance of the resultant weld metals are summarized graphically in Fig. 7. Elongation and crack resistance of these experimental molybdenum-manganese alloys were also altered markedly by changes in phosphorus content of the weld deposit. As phosphorus content decreased, the resultant weld metals were appreciably more ductile and resistant to cracking as measured by the root-bead crack test.

Molybdenum-Manganese Alloys Containing 12% Manganese

In earlier work, considerable difficulty was encountered in the preparation of crack-free welded specimens for tensile and impact testing using conventional molybdenum-manganese electrodes. A single exploratory test was added to determine if over-all properties of an alloy of this type could also be improved by a reduction in phosphorus.

Cracking tendencies of the weld deposit were altered sharply by the reduction in the phosphorus level of the alloy, Fig. 8. The alloy with a conventional amount of phosphorus was crack sensitive as evaluated by the armor-weld crack test. A low-phosphorus counterpart of this alloy, on the other hand, exhibited no such cracking tendencies under like test conditions. Ductility, yield, tensile and low-temperature impact strengths of the lower phosphorus content, molybdenum-manganese alloy were, in all cases, superior to those of the alloy containing a conventional amount of phosphorus, Fig. 9. With the particular alloy balance employed, however, none of these latter improvements was as marked as those encountered in similar tests of nickel-manganese materials.

The relatively low impact strengths of this molybdenum-manganese alloy as compared to those of the nickel-

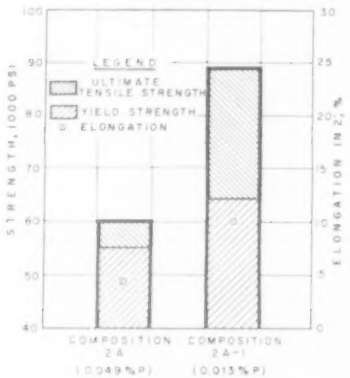

Fig. 8 Comparative mechanical properties of two molybdenum-manganese alloys containing about 12% manganese

manganese alloys tested were probably due to a difference in stability of the austenitic phase. After only 10% of elongation, fractured tensile specimens showed some transformation to martensite. The weld metal exhibited magnetic characteristics equal to those of an austenitic stainless steel containing about 4% of ferrite. Transformations of this type were not observed in any of the nickel-manganese alloys examined.

Summary

Phosphorus content of austenitic manganese weld metals proved a more potent factor in alloy balance than generally recognized previously. Seemingly minor shifts in phosphorus content produced drastic changes in properties of the weld deposit.

Nickel-manganese weld metals with reduced phosphorus contents in the range of 0.01 to 0.02% had outstanding tensile strength, ductility and crack resistance. Phosphorus contents of about 0.035% appeared the maximum that could be tolerated without impairment of properties of the weld deposit.

Exploratory work indicated that the general response of molybdenum-manganese weld metals to reductions in phosphorus content paralleled those observed in nickel-manganese weld metals.

In all instances, low-phosphorus-content austenitic manganese weld metals had superior strengths and crack resistance than those of their higher-phosphorus counterparts. At the same time, however, magnitude of the improvements resulting from the reduction in phosphorus level varied somewhat. This latter variation undoubtedly is a function of alloy balance of major constituents in each of the specific alloy combinations investigated.

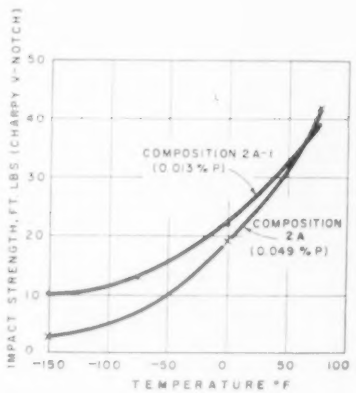

Fig. 9 Impact strength of two lower manganese content molybdenum-manganese weld metals

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FABRICATION AND SERVICE FACTORS INVOLVED IN FAILURE OF WELDED STEAM RECEIVERS

A study of cracking associated with the welds in steam accumulators in a carrier service application

BY A. J. BABECKI AND P. P. PUZAK

ABSTRACT. Base-metal cracking in the vicinity of nozzle and manhole reinforcement pads was discovered recently in several 65-in.-diam catapult steam receivers aboard four naval aircraft carriers after 1 to 1½ yr of service. The cracking was evident only on the inside surface of the receivers, generally following the toe of the fillet weld between shell and reinforcement pad. To date, cracking has been discovered only on receivers which were fabricated by one manufacturer; however, these have been in service longer than similar receivers built by other manufacturers. This paper covers the Naval Research Laboratory investigation of cracked sections taken from three receivers.

A. J. Babecki and P. P. Puzak are associated with the Metal Processing Branch, Metallurgy Division, U. S. Naval Research Laboratory, Washington, D. C.

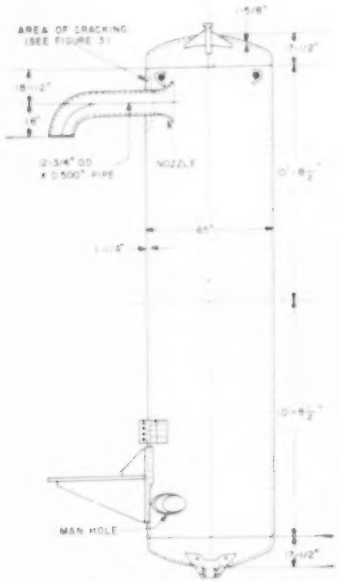

Fig. 1 Schematic drawing showing over-all dimensions and contour of catapult steam receiver

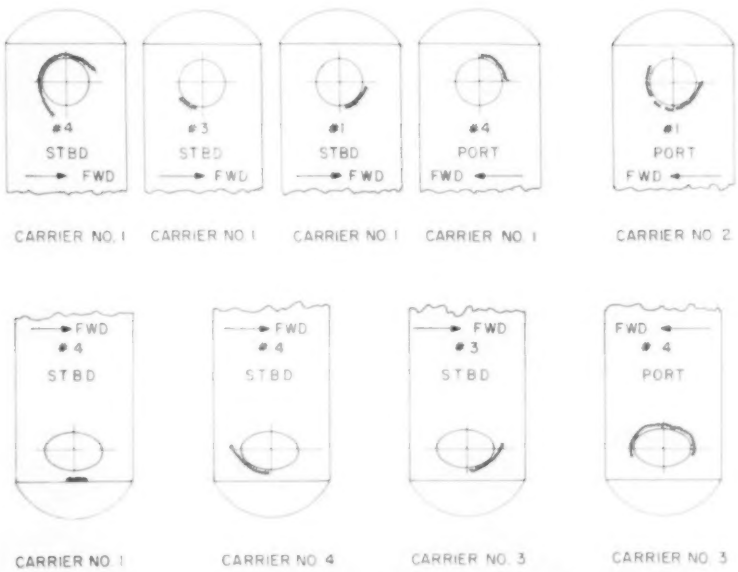

Fig. 2 Summary of cracking found in accumulator nozzle (*top*) and manhole (*bottom*) areas on four aircraft carriers; all views from inside receivers

Chemical and mechanical tests indicated that the steel used was as specified (A212), although the steel from two of the receivers did not quite meet ASME pressure-vessel-code minimum strength requirements. Fabrication defects in the form of porosity, undercutting and poor fitup were found in all three receiver sections. Normal oxidation scale on the inside receiver surfaces was similar to that found on the crack surfaces; however, operating conditions were such as to preclude the requirement of unusual corrosive conditions for the cracking. Typical fatigue-type markings of crack propagation were found on the crack surfaces emanating from weld-metal porosity. Microscopic examination disclosed the cracks to be wholly transgranular; slow propagation of the fissures was indicated by the heavily deformed metal contiguous to the line of propagation. Brittle fracture was not involved.

Although normal elevated-temperature oxidation and a slight material deficiency were present, these are not considered to be primary factors responsible for these failures. Fabrication defects and stresses resulting from design particulars are believed to be the principal causes for the development of these premature fatigue failures under normal accumulator service conditions.

Introduction

Some U. S. Naval aircraft carriers are equipped with eight outboard steam receivers which are used in the cyclic operation of catapulting aircraft into the air. These 25-ft long by 5½- and 6-ft diam pressure vessels are suspended vertically, four on each side of the ship, and interconnected in groups of four by manifold piping which

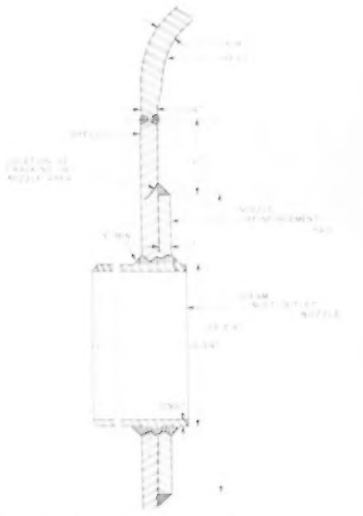

Fig. 3 Detail drawing of accumulator nozzle area showing dimensional and fit-up requirements and location of cracking

Fig. 4 Inside surface view (*top*) of cracked nozzle section typical of both nozzle and manhole area failures. Close-up (*bottom*) of cracking at toe of reinforcement-pad-to-shell fillet weld

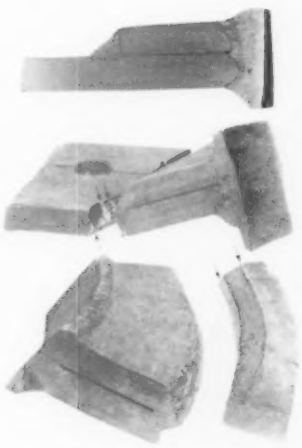

Fig. 5 Variations in fitup between shell and reinforcement pad evident in nozzle sections

Original crack surfaces (dark areas) are distinguishable from brittle fracture surfaces (light areas at arrows) after being broken open at low temperatures for examination

carries steam from the ship steam system. The over-all dimensions and contour of such catapult steam receivers or accumulators are shown schematically in Fig. 1. These vertical, cylindrical pressure vessels having ellipsoidal heads were designed in accordance with Section VIII, ASME Boiler and Pressure Vessel Code for maximum working pressures of about 600 psig at operating steam temperatures of about 650° F. In normal operation, however, the maximum steam pressure available to the receivers is about 550 psig, with steam temperatures probably not exceeding 525° F. (The aircraft currently carried by these ships do not require maximum initial pressure; consequently, a limited survey indicates that virtually all operation of the catapult receivers had been with an initial pressure of 250 psig or less.) The steam-inlet nozzle (near the top head) is also used as the steam-outlet nozzle. The vessels are fabricated of 1 1/8-in. and 1 3/8-in. thick A-212 Grade B firebox-quality shell plate with 1-in. thick heads. (This is the conventional high-tensile-strength C-Si steel used for boilers and other pressure vessels.) Specifications require the radiographing of all shell seams; magnetic-particle inspection of welds around nozzles, pads and attachments; stress relieving of the completed vessels; and shop hydrostatic-pressure tests at 1 1/2 times the working pressure.

During a recent inspection of the steam accumulators aboard one carrier, visible cracking of the shell plate was discovered in the heat-affected zone of the reinforcement-pad weld of the steam inlet-outlet nozzle. Shortly thereafter, similar cracks were discovered in the manhole area (Fig. 1, near the bottom head) of an accumulator aboard another carrier. The extent of cracking in this vessel was initially believed to be minor; the cracks were not manifest on the outside surface of the vessels; on the inside surface, they appeared as incipient, intermittent, hairline crack indications. However, grinding of these manhole crack indications for weld repairs revealed the seriousness of the cracking involved. At subsurface levels, the cracks were observed to be continuous and extended in length for approximately 5 ft and in depth for 1 in. or more. Subsequently, close examination of other accumulators aboard these and other carriers disclosed similar cracking in a total of eight steam accumulators aboard four different carriers.

The same material (A-212) has been used in the fabrication of almost all of the steam-accumulator vessels involved in carrier construction. The design of these vessels, however, varies with different ships (e.g., some of the A-212 accumulators are horizontal rather than vertical). It was ascertained that all of the cracked receivers had been built by one industrial fabricator. These receivers, however, had been in service longer than similar receivers built by other fabricators. An immediate investigation was considered mandatory

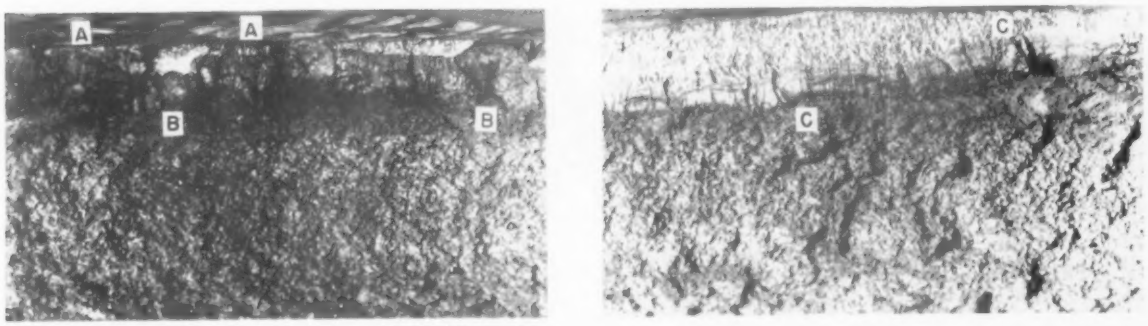

Fig. 6 Macrographs of crack faces in vicinity of fusion line

Light fracture surfaces indicate metal broken at low temperatures to open cracks for examination. Note intermittent breakthrough of crack to surface (*A*) porosity (*B*) and fatigue-type markings (*C*)

to establish whether continued operations with these vessels would be safe or whether immediate replacements by newly designed accumulators should be proposed. Because of the possible implications of these findings to our carrier fleet and contemplated construction program the Naval Research Laboratory (NRL) was authorized by the Bureau of Ships (Code 537) to investigate and determine the cause of the observed cracking.

Description and Macroscopic Examination of Casualty Material

The cracking discovered in various accumulators to date is summarized in Fig. 2. All cracks, except that in the head-to-shell seam weld near the manhole area of the No. 4 starboard receiver of Carrier No. 1, were associated with the fillet welds between shell plates and reinforcing pads. A detail drawing of the fitup and reinforcing-pad fillet weld required for the steam inlet-outlet nozzle is shown in Fig. 3. The accurate fitup between shell and reinforcing pad shown in Fig. 3 is generally aimed for in pressure-vessel construction in order to minimize structural "notch" effects. The general appearance and location of cracks which occurred in manhole and nozzle areas were similar to that shown in Fig. 4 for one of the steam inlet-outlet nozzle sections received for examination.

Half sections of two nozzles and one manhole from receivers of three carriers were examined. The exceptionally poor fit-up between reinforcement pad and shell plate illustrated in Fig. 4, bottom, was found to be characteristic of fabrication employed for each of these sections. Variations in fit-up between shell and pad of $\frac{1}{16}$ to $\frac{3}{16}$ in. were observed in other locations, Fig. 5. In addition, gross porosity was evident in all welds, and undercutting characterized the abrupt change in cross-sectional thickness at the fillet weld between shell and reinforcing pad.

Visual examination of the separated crack surfaces (Fig. 5, center and bottom) disclosed them to be covered with two layers of scale. Adjacent to the metal, a tightly adhering, blue-gray oxide layer covered all crack surfaces; an intermittently distributed reddish, rust-colored oxide deposit covered portions of the major crack surface area. The thin, blue-gray oxide scale was similar in appearance to the naturally protective oxide-scale layer which covered the inside surface of the accumulator. Such blue-gray films are generally formed on ferritic steels in the presence of oxygen at elevated temperatures. X-ray diffraction patterns of the reddish, rust-colored oxide showed it to contain alpha-Fe_2O_3 (an oxide which forms in the presence of oxygen only at temperatures above approximately 200° F). The reddish oxide is believed to result from the conversion of corrosion products formed during out-of-service periods.

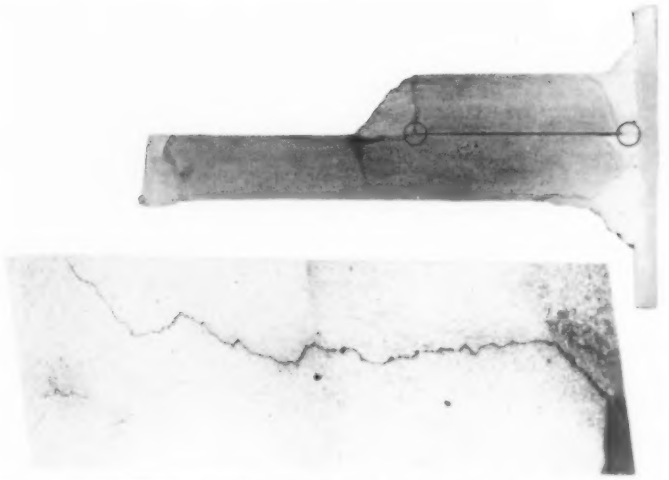

Fig. 7 Example of fatigue cracking found at root of fillet welds of nozzle area reinforcement pad (encircled areas). Etchant: 2% Nital. X 50. (Reduced by one-half upon reproduction)

Table 2—Tensile Properties of Casualty Material

Specimen	*Carrier*	*Yield point, psi*	*Ultimate tensile strength, psi*	*Elongation in 2 in., %*	*Reduction in area, %*
1	No. 1	40,000	71,750	30	55.3
2	No. 1	41,250	71,500	31	58.7
1	No. 2	33,250	67,500	32	62.0
2	No. 2	32,500	67,500	34	62.2
1	No. 3	33,000	67,750	32	61.5
2	No. 3	34,500	68,250	33	62.7
ASME A-212 Specification, Grade B Firebox		38,000*	70,000 85,000	22*	

* Minimum.

Table 1—Chemical Composition of Casualty Material

Element, %	*Carrier No. 1*			*Carrier No. 2*			*Carrier No. 3*			*ASME A-212 Specification for Grade B Firebox-Quality Steel*	
	Shell	*Weld*	*Pad*	*Shell*	*Weld*	*Pad*	*Shell*	*Weld*	*Pad*		
C	0.28	0.07	0.27	0.30	0.08	0.26	0.29	0.07	0.27	0.33	max
Mn	0.84	0.29	0.52	0.77	0.32	0.75	0.77	0.34	0.74	0.90	max
P	0.008	0.017	0.002	0.005	0.004	0.022	0.029	0.027	0.012	0.035	max
S	0.048	0.028	0.028	0.040	0.031	0.028	0.030	0.024	0.028	0.04	max
Si	0.23	0.17	0.22	0.24	0.19	0.21	0.28	0.20	0.23	0.15–0.30	
Cu	0.01	0.10	0.05	0.02	0.15	0.07	0.04	0.02	0.14		
Ni	0.04	0.05	0.05	0.04	0.06	0.05	0.04	0.04	0.15		
Cr	0.09	0.08	0.08	0.09	0.08	0.08	0.04	0.07	0.15		
Mo	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03		
V	0.01	0.02	0.03	0.01	0.03	0.02	0.02	0.04	0.03		
Ti	Nil	0.02	Nil	Nil	0.01	Nil	Nil	0.02	Nil		

Table 3—Diamond Pyramid Hardness (1-Kg, Vickers) of Reinforcement-Pad-to-Shell Fillet-Weld Area (Average of Three Traverses)

NRL weldment with Carrier No. 1 casualty steel*			*Service weldments†*				
					DPH		
Condition	*Area‡*	*DPH*	*Condition*	*Area‡*	*Carrier No. 1*	*Carrier No. 2*	*Carrier No. 3*
As-deposited	W	180					
	HAZ	214					
	BM	203					
After stress-relief No. 1	W	179	As-received	W	195	217	152
	HAZ	218		HAZ	223	219	188
	BM	182		BM	189	185	173
After stress-relief No. 2	W	162	After NRL stress relief	W	184	207	153
	HAZ	191		HAZ	189	194	175
	BM	168		BM	168	173	164

* Fillet weld made with E6010 electrodes.

† Fillet welds specified to be gas-procedure Spec. No. 2 for submerged-metal-arc deposits.

‡ W = weld, HAZ = heat-affected zone, BM = base metal.

Detailed examination was made of the separated crack surfaces in the vicinity of the weld fusion line. From numerous subsurface-porosity indications observed in the weld metal, distinct evidences of fatigue (conchoidal-ring fracture patterns) were found emanating toward the surface, Fig. 6. The crack on the internal surface of the vessel appeared to be discontinuous because of the intermittent progression to the surface of several different fatigue cracks.

The geometrical configuration encountered in the vicinity of the reinforcement-pad fillet weld is generally recognized to be conducive to stress concentrations which may result in an increase of the local stress to several times the magnitude of the design membrane stress. Accordingly, the location of the principal crack at the toe of the pad fillet weld is as expected under normal conditions of cyclic operations.[1] It is considered possible that severe thermal strains are developed in the vertical-design accumulator vessels as the result of a single nozzle being used for both steam-inlet and steam-outlet purposes. Several cracks (those shown in Fig. 7 are typical), which were observed in the root pass of the reinforcement-pad fillet weld and nozzle wall weld, are believed to indicate the development of high thermal strains during normal catapult operations.

Results of Chemical and Mechanical Tests

Drillings for chemical analysis were removed from the shell, weld and reinforcement pad of each of the three receiver sections. The results, Table 1, indicate that the shell and reinforcing pad conform to ASME specifications for A-212 Grade B firebox-quality steel. The weld compositions appear to be that of low-carbon mild-steel welds equivalent to E6010 electrode deposits.

Two standard 0.505-in. diam tensile specimens were machined from the shell plate of each receiver section and tested at room temperature. Yield points were determined by the drop-of-beam method. The duplicate results, Table 2, show close agreement with each other; however, the specimens from Carriers No. 2 and No. 3 did not meet minimum ASME strength requirements for A-212 Grade B firebox-quality steel. All tensile-specimen fractures occurred within the gage length and were of the cup-cone type.

In order to determine whether the receivers had been given a thermal stress relief after fabrication, a simulated fillet weld was made at NRL with portions from one of the failed accumulator shells. A series of microhardness surveys (1-kg load, Vickers DPH) was subsequently conducted across the weld zones of adjacent, cross-sectional, surface-ground slices (mating faces) of as-deposited NRL-welded, as-received, and NRL-stress-relieved (1150° F) samples, Table 3. The hardness value of the heat-affected zone of the as-deposited NRL-welded samples generally exceeded those values obtained in the as-received failure sections; the hardness values of the as-received sections compared favorably with the hardness value of the NRL-welded sample which was given a single stress relief. In addition, the hardness values of the failed receiver sections after a single stress relief at NRL simulated that of the NRL-welded sample after two stress-relieving treatments. Accordingly, it is deduced that the failed receivers were given a

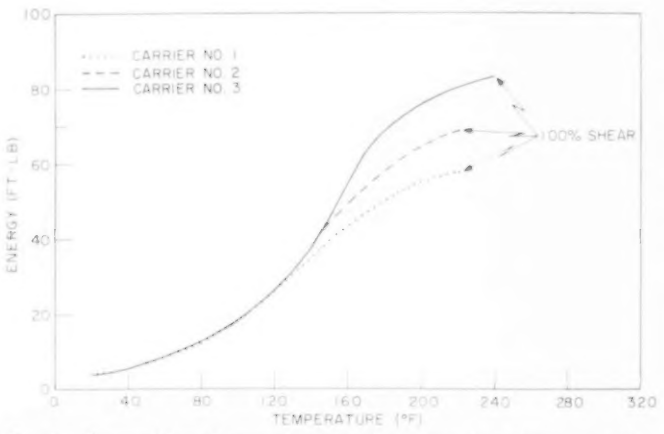

Fig. 8 Charpy-V-notch impact curves of receiver shell plates. Specimens were oriented with long axis parallel to the rolling direction and notch perpendicular to plate surface

Fig. 9 Appearance of cracking in Carrier No. 1 receiver; inside surface at toe of reinforcement-pad-to-shell fillet weld

Etchant: 2% Nital. X 50. (Reduced by one-half upon reproduction)

final thermal stress relief after fabrication.

Macroscopic examinations of the as-failed accumulator sections revealed that brittle fracture was not involved in the cracking which developed. However, because of recent experience involving brittle fractures in pressure vessels, it was requested that Charpy-V impact transition curves be established for the A-212 shell material. Figure 8 shows the average impact transition curves of the three receiver-shell plates established by tests of at least two Charpy specimens at each test temperature. Specimens were also machined from locations adjacent to both the inside and outside receiver surfaces, but no significant differences in their transition curves were noted. The average Charpy-V curves are similar, differing only slightly in the maximum energy level reached at the 100% shear temperatures. From these transition curves, it is estimated that brittle-fracture initiation would be potentially possible in these steels only at (and below) approximately 80 to 100° F.

Microscopic Observations of Casualty Material

Microscopic examination was made of several cracked areas from Carriers No. 1 and No. 2 nozzle sections (the cracking discovered in the Carrier No. 3 section had been removed by grinding). Generally, the cracks broke the surface of the receiver at the toe of the weld (i.e., the abrupt surface junction between the hardest portion of heat-affected zone and weld metal). Below the surface, the crack continued through weld metal or heat-affected zone, and finally into the unaffected shell plate for approximately three-fourths or more of the plate thickness. The features evident in the photomicrographs of Fig. 9 are typical of crack areas around the periphery of nozzles from both carriers. The cracks progressed along one principal path in which evidence of oxide scale throughout the length of the crack was observed. In many cracked areas of the base metal, two apparently parallel cracks were observed to be separated by highly deformed metal developed as the result of cyclic fatigue action, Fig. 10. In all cases, the general microstructure of the metal in the vicinity of the cracks appeared to be normal for this class of steel.

Figure 11 illustrates the wholly transcrystalline propagation observed at the extreme tip of the cracks contained in the section from Carrier No. 1. In addition, wholly transcrystalline oxide penetrations (branches of disconnected fatigue cracks) in different stages of progression were also observed in other apparently noncracked locations of the pad fillet-weld area of the same section, Fig. 12.

Summary, Discussion and Conclusions

In a review of several Pressure Vessel Research Committee (PVRC) research projects, the effect of plastic fatigue on pressure-vessel materials and design has recently been summarized.[7] Of significance to the subject accumulator cracking problem, these PVRC studies have shown:

1. Fatigue strength is reduced by any factor which introduces a local increase in cyclic strain.

2. Of the various mechanical factors which influence fatigue resistance, by far the most important is the stress-raising action of notches or other discontinuities in the steel section.

3. Superimposed surface defects will lower fatigue strength.

Fig. 10 Portion of crack path in shell of Carrier No. 1 receiver in nozzle area

Note twin-path appearance of crack and cold-worked metal within. Etchant: 2% Nital. X 50. (Reduced by one-half upon reproduction)

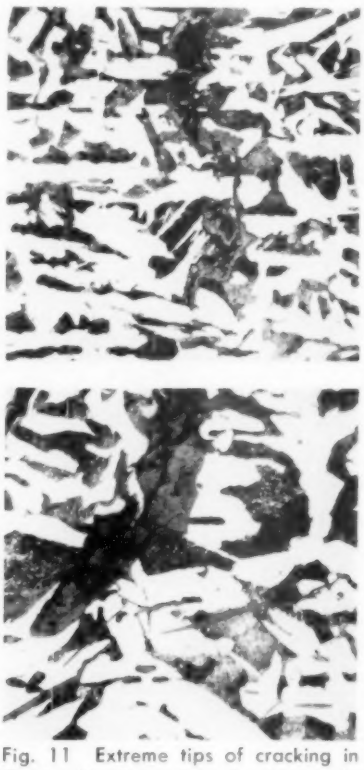

Fig. 11 Extreme tips of cracking in Carrier No. 1 receiver showing oxide formation in the finest fissure and transgranular path of crack propagation

Etchant: 2% Nital. X 250 (upper photo) and X 500 (lower photo). (Reduced by one-half upon reproduction)

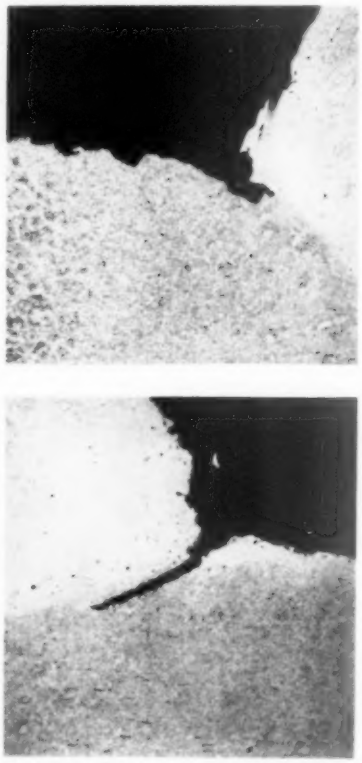

Fig. 12 Cracking in Carrier No. 1 receiver nozzle area fillet weld in two stages of progression

Etchant: 2% Nital. X 50. (Reduced by one-half upon reproduction)

4. The effective strain-concentration factor may be secondarily dependent on material characteristics and not just a function of geometry alone.

5. In the absence of corrosive environments, pressure-vessel steels exhibit little change in fatigue resistance over a temperature range of 0 to 650° F.

Even though A-212 materials were not included in the PVRC studies, A-212 has been code approved and used widely in land-base installations with good results. The PVRC findings for other pressure-vessel steels are generally considered to apply to the A-212 steels. Under similar conditions of design and superimposed fabrication deficiencies shown to exist in the subject accumulator vessels, premature fatigue failure could therefore be expected for any of the steels conventionally used for pressure-vessel service.

At the time of discovery of the failures, the maximum length of service for any of the cracked receivers was approximately 1 to 1½ years. Under severe corrosive conditions, such relatively short service life might be expected. However, macroscopic examination of all receiver interiors disclosed no evidence of abnormal corrosion attack. No pitting or heavy scaling was found; the interior vessel surfaces were covered with a thin adherent blue-gray oxide topped by a reddish, powdery, oxide layer, and the same scale conditions prevailed on the crack surfaces themselves. Microscopic examinations did not reveal any of the definite, typical indications which characterize failures involving abnormal corrosion as the principal agent.[3] It is considered possible that propagation of these premature failures was assisted by simultaneous oxidation at normal operating temperatures of each newly developed fatigue crack. The conditions existing in the subject accumulators, however, were such as to preclude this normal corrosion (oxidation) process from being the *determining* factor primarily responsible for the initiation or propagation of these premature failures.

The subject vertical receiver design is considered at this time to have contributed to the development of these premature failures. As the result of movements of the inlet-outlet nozzle piping, normal operations of the accumulator vessels are expected to create bending moments in the pressure-vessel shell. The relative location of the nozzle and manhole openings and concomitant proximity of the reinforcement-pad fillet welds to the shell-to-header seam welds, and the general restraint conditions in these areas are all conducive to the development of increased local strains with resulting reductions in fatigue strength. Under such conditions, the superposition of fabrication defects in these areas normally would be expected to promote premature fatigue failures. Accumulators of similar design but of a different manufacturer which have not been in service as long as the failed vessels have reportedly not developed similar cracking problems. However, at least two indications of base-plate hairline cracks have been noted in these accumulators. The cracks were observed to be associated with plate defects (surface laps or laminations) near manhole areas and progressed outward roughly normal to the surface of the fillet weld.

The subject accumulator failures are deduced to be premature fatigue failures developed under normal accumulator service conditions. Failure is believed to have started in one or several places, more or less simultaneously, as the result of mechanical stresses and strains developed at particularly unfavorable locations involving fabrication defects. A-212 material characteristics, *per se*, are not considered to be a primary factor responsible for these premature failures. Although the shell plates from two accumulators fell slightly below minimum specified strength properties, similar failures were developed in other receiver shell plates which did pass minimum strength requirements. Irrespective of the pressure-vessel material employed, if the fabrication quality shown in Figs. 4, 5, 6 and 7 is typical of that existing in all of these receivers, continued operations with repaired or other receivers of similar design could not be expected to be trouble free.

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Acknowledgment

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RESEARCH NEWS

Ultrasonic Testing

Research and Development Leading to the Establishment of Ultrasonic Test Standards for Aircraft Materials. A. D. Quinn, R. D. McKown, J. C. Folz, and W. C. Hitt, Ultrasonic Testing and Research Laboratory for Wright Air Development Center, U. S. Air Force, October 1957. 133 pages. (Order PB 131564 from OTS, U. S. Department of Commerce, Washington 25, D. C., $3.50.) Ultrasonic testing is recognized by material producers and engineers as one of the best nondestructive methods of testing metallic materials for subsurface discontinuities. Data contained in this volume provide assistance in setting up reference standards for ultrasonic testing of various alloys. It was compiled from results of the determination of signal response variables which may be caused by manufacturers' methods, such as rolling or forging, the conditions of heat treatment, grain flow direction, differences in machined surface finishes, different surface angularity and the effects of various convex and concave radii machined on the top surface. Comparisons are made between test results obtained from different alloys of the same group, different crystals and various frequencies and gain settings.

Electron Microscope

A new 6-page folder giving engineering data on the Norelco EM-75B electron microscope is available from the Instruments Division, Philips Electronics, Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.

Reprinted from the Norelco Reporter, the text explains the electron optical system, filament replacement, lens system and viewing screen, vacuum system, power supply and instrument operation.

Illustrated with photos, drawings and micrographs, the new folder deals in detail with condenser, objective and projector lenses. Other sections cover specimen holder and airlock, 35-mm roll film cassette, plate holder, beam wobbler, electromagnetic alignment and mechanical stability.

LOW CRACK SENSITIVITY OF STEEL JOINT BY CO_2-O_2 ARC WELDING

Hydrogen content and crack sensitivity of welds deposited by this new Japanese process and by other welding processes are compared

BY H. SEKIGUCHI AND I. MASUMOTO

SYNOPSIS. In Japan, a new gas-shielded metal-arc-welding process has recently come to be applied automatically and semiautomatically. In this process, a mixed gas of carbon dioxide (CO_2) and oxygen (O_2) is supplied around the arc and molten pool and a bare steel wire containing suitable quantities of deoxidizers is used as a metal electrode.

In this report, an outline of this process is given first; then the results of measurements on hydrogen contents and crack sensitivities of steel joints obtained by various processes are compared.

The hydrogen content of the weld by this process is very low in comparison with those by other processes. Accordingly, the crack sensitivity of joints made by the former process is also lower than that of joints made by the latter process.

Introduction

Metal-arc welding processes are applied mainly for manual welding with covered electrodes. But these processes are occasionally utilized automatically. In that case, a bare wire is used with or without flux. In the case of automatic metal-arc welding without flux, a shielding gas or gaseous mixture is supplied around the arc and molten pool. This gaseous shielding excludes the air from that part and protects the traveling molten metal globule and deposited molten metal.

Various gases or gaseous mixtures used for this purpose are classified into the following three groups:

1. Reducing gas (e.g., A + H_2, CO_2 + CO)
2. Inert gas (e.g., A, He)
3. Oxidizing gas (e.g., A + O_2, CO_2, CO_2 + O_2)

Earlier, reducing gas or inert gas was considered to be suitable for shielding. But, at present, oxidizing gases are mainly used for steel. In the latter case, according to the oxidizing property of shielding gas, the molten metal from the electrode and base metal is oxidized and a small amount of slag is produced. This slag seems to have beneficial effects on the state of deposition and on the appearance of the bead.

In regard to gaseous mixture of CO_2 and O_2, the authors confirmed these facts: the amount of slag produced increases with the increment of oxygen content in gaseous mixture. Also, the beneficial oxidizing effects mentioned above become more evident with increasing oxygen content.

On the other hand, the oxidizing action of the shielding gas leads to the formation of blowholes in the weld metal, if the amount of deoxidizer in the molten steel is insufficient. Therefore, in metal-arc welding shielded with strongly oxidizing gaseous mixture, an electrode containing sufficient amounts of deoxidizers must be used.

Based on these experimental facts, a new gas-shielded metal-arc welding process, the CO_2-O_2-supplied arc-welding process with a steel electrode containing sufficient and suitable amounts of deoxidizers, was originated by the authors and has recently come to be applied automatically and semiautomatically in Japan.[1]

In this report, first of all, a description of this process is given. Next, the results of measurements on hydrogen contents and crack sensitivities of joints by various processes are compared. Further, the results of experiments on the dew points of supplied gases are described; hereby it is emphasized that the gas with the lowest possible dew point is preferable.

Outline of Process

The main points of the CO_2-O_2 arc-welding process with a steel electrode containing deoxidizers are as follows.

Gas Supplied for Shielding

A gaseous mixture of carbon dioxide and oxygen is supplied for shielding the arc and molten metal. The main component of the mixture is CO_2 and the gas O_2 is added intentionally. The volume percentage of O_2 in the mixture can be controlled in accordance with chemical compositions of base steel and electrode steel, with an eye on the mechanical properties required for weld metal. For example, a flow of gaseous mixture, consisting of 20 cfh of CO_2 and 11 cfh of O_2, is adopted commonly for mild steel.

The carbon dioxide gas dissociates as follows in the high temperature area in the neighborhood of the arc: $CO_2 \rightleftarrows CO + O_2$. This gaseous mixture reacts with the molten steel as an oxidizing gas.

In the CO_2-O_2 arc-welding process, a gaseous mixture of CO_2 and O_2 is supplied from the beginning. Consequently, a more strongly oxidizing gaseous shield is created than with the case when CO_2 only is supplied.

Steel Wire Used as Electrode

Steel wires containing sufficient and suitable amounts of deoxidizers are used in this process. The main deoxidizers are silicon and manganese; further, titanium and others may be added. The ratio of silicon and manganese contents is important for producing the slag easily separable from the molten metal. The authors consider that the point showing the right chemical composition of steel electrode should be in the Field H [2] between the curves $G'F'$ and $Q'D'$ of Fig. 1. Further, the range, in which suitable points are found, changes in accordance with the chemical composition of the base steel. For example, the suitable points for killed mild steels should exist in the field $F'IJ$, and those for rimmed mild steels in the field $F'KL$. These conclusions are based on experimental results. The points X (0.04% C, 0.59% Si, 1.64% Mn, 0.21% Ti) and Y (0.06% C, 0.75% Si, 1.78% Mn,

H. Sekiguchi is Professor and I. Masumoto is Assistant, Department of Metallurgy, Faculty of Engineering, Nagoya University, Nagoya, Japan

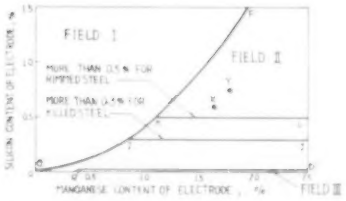

FIELD I
FIELD II
FIELD III
MORE THAN 0.5 % FOR RIMMED STEEL
MORE THAN 0.5 % FOR KILLED STEEL
SILICON CONTENT OF ELECTRODE, %
MANGANESE CONTENT OF ELECTRODE, %

Fig. 1 Manganese and silicon contents of electrodes for CO_2-O_2 arc-welding process

Kind of slag separated from molten steel is as follows: in Field I, solid SiO_2; in Field II, FeO-MnO-SiO_2 liquid solution unsaturated with SiO_2; in Field III, FeO-MnO solid solution

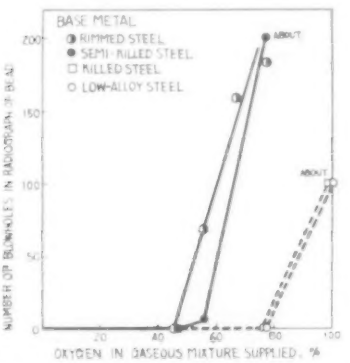


Fig. 2 Effect of oxygen in gaseous mixture on the porosity of the weld bead

0.19% Ti) are examples applicable to both rimmed and killed steels.

Effects of Slag Formation

Because of the strongly oxidizing property of shielding gas, a relatively large amount of slag is produced in this process. Through the influence of this slag, the state of deposition is improved, with little spattering; covering of slag on bead is uniform, excoriation of slag easy and appearance of bead good.

Effects of Deoxidizers

When a conventional electrode is used in CO_2-O_2 arc welding, a very porous weld metal results. In this process, sufficient amounts of deoxidizers are transferred into the molten

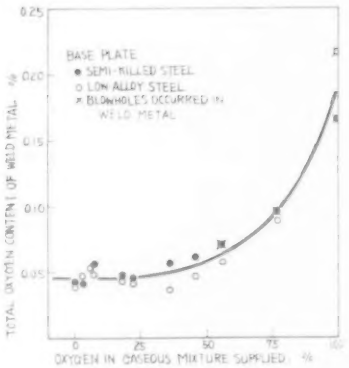

BASE PLATE
SEMI-KILLED STEEL
LOW ALLOY STEEL
BLOWHOLES OCCURRED IN WELD METAL
TOTAL OXYGEN CONTENT OF WELD METAL, %
OXYGEN IN GASEOUS MIXTURE SUPPLIED, %

Fig. 3 Relation between total oxygen content of weld metal and that of gaseous mixture supplied for shielding

Total oxygen content of weld metal was measured by the vacuum-fusion method

Chemical Analyses, %, of Base Plates and Electrode

	C	Si	Mn	Al	Ti
Semikilled steel	0.12	0.08	0.60	0.008	..
Low-alloy steel	0.17	0.53	1.27	0.074	..
Electrode	0.04	0.59	1.64	..	0.021

metal from the electrode. Consequently, the oxygen content of the weld metal does not increase appreciably and no blowholes occur in the weld metal so long as the oxygen content of the supplied gaseous mixture does not exceed a certain limit. But when a gaseous mixture containing too much oxygen is used, blowholes occur in the weld metal as illustrated in Figs. 2 and 3. Therefore, a suitable gaseous mixture must be selected with a suitable electrode for the base material.

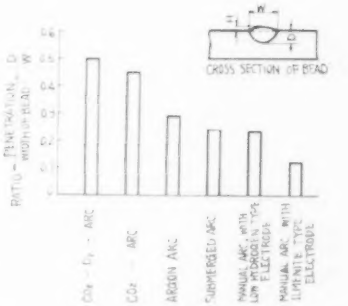

CROSS SECTION OF BEAD
RATIO = PENETRATION / WIDTH OF BEAD
CO_2 + O_2 - ARC
CO_2 - ARC
ARGON ARC
SUBMERGED ARC
MANUAL ARC WITH LOW HYDROGEN TYPE ELECTRODE
MANUAL ARC WITH ILMENITE TYPE ELECTRODE

Fig. 4 Comparison of various welding processes, concerning the ratio of penetration to width of bead

D = penetration, W = width of bead, H = height of reinforcement. Thickness of base plate = 13/32 in.

Mechanical Properties of Weld Metal

The mechanical properties of welds produced by this process are by no means inferior to those obtained by other processes. And these values can be controlled by changing the oxygen content of the supplied gas for shielding. Table 1 shows this relationship.[3]

Deposition Rate and Penetration

In this process, exothermic reactions take place between oxygen and deoxidizers in molten steel. The heat generated in this reaction raises the temperature of molten steel fused with the arc. Accordingly, the penetration of bead is extremely large. Figure 4 shows this circumstance. Further, in view of the fact that an extraordinarily high density of welding current is allowed in this process, weight of

Table 1—Mechanical Properties of Weld Metal Deposited by CO_2- and CO_2-O_2 Arc-Welding Processes

Kind and flow of supplied gas, cfh	*Mark of electrode*	*Ultimate tensile strength, kg/mm²*	*Elongation,* %*	*Charpy value at 20° C, kg-m/cm²*
CO_2, 38	X	54.6	27.9	21.9
	Y	49.1	32.7	25.8
CO_2, 29	X	46.3	33.0	19.5
O_2, 11	Y	43.6	36.3	20.1

* Gage length 50 mm, diam 12.5 mm.

Table 2—Welding Conditions of Vee Butt Joints

	Electrode		*Welding transformer*				
Process	*Coating*	*Diam, in.*	*Characteristics*	*Max welding current, amp*	*Arc voltage, v*	*Welding current, amp*	*Traveling rate, ipm*	*Sum of passes*
CO_2-O_2 arc-welding process	Bare	3/16	Constant voltage transformer rectifier	500	27–38*	320–480*	12 13/16–20*	7–10
Manual-arc-welding process	Low-hydrogen type	3/16	ac	285	24–25	230–240	6 1/16–8 1/4	9–12
	Ilmenite type†	3/16	ac	285	27–28	200–240	8 1/4–9 13/16	9–12

* Some passes in the beginning of welding were deposited under higher voltage and lower current.
† This type electrode is used most commonly in Japan.

deposition in unit time is very large even when an electrode of smaller diameter is used than with the manual arc-welding process.

Hydrogen Content and Crack Sensitivity

The hydrogen content of welds made by this process is very low compared with that obtained with other processes. The crack sensitivity of a welded part is also less than that with other processes. These facts are treated in detail in the ensuing sections of this report.

Economical Consideration

Carbon dioxide and oxygen are inexpensive compared with inert gases such as argon or helium. Expensive flux is not necessary. Deposition rate is very high and penetration is deep. Continuous bare-steel wire is fed as an electrode either automatically or semi-automatically.

Thus, the over-all welding cost associated with this process is low in comparison with the cost of other processes.

Frequency of Fisheye Occurrence

Welding of Vee Butt Joint

Many vee butt joints were made by the CO_2-O_2 arc-welding process. For comparison, many similar joints were also made by manual arc welding with covered electrodes: low-hydrogen-type electrode and ilmenite-type electrode, which are used most commonly in Japan. The form and dimension of the joint used were based on the "Tentative Specifications for Mild Steel Arc Welding Electrodes" (ASTM Designation: A 233 – 48 T).[3] The welding conditions are tabulated in Table 2.

Tension Test

All-weld-metal tension test pieces, conforming to the referred specifications,[3] were taken from the weld metal of vee butt joints. The diameter of the parallel part of the testpiece is $2^1/_4$ in. and the gage length is 2 in. Tension tests were carried out within 48 hr after welding. Ultimate tensile strength, elongation and reduction of area were measured. Table 3 lists these results. Then the fractured surface was observed and the existence or nonexistence of fisheyes was investigated. The frequency of fisheye occurrence is also contained in Table 3.

Mechanical Properties

According to the results shown in Table 3, mechanical properties of weld metal obtained by CO_2-O_2 arc welding are by no means inferior to those by manual-arc welding with coated electrode.

Frequency of Fisheye Occurrence

According to the data of Table 3, fisheyes are rarely observed in the weld metal which was deposited by the CO_2-O_2 arc-welding process, the frequency being only 5%. The corresponding figure for the manual-arc welding is 25% with a low-hydrogen-type electrode and 95% with an ilmenite-type electrode.

From this it is clear that the frequency of fisheye occurrence in case of the CO_2-O_2 arc-welding process is very small compared with manual-arc welding with covered electrodes.

Hydrogen Content of Weld Metal

Preparation of Specimen and Measurement of Hydrogen Content

The preparation of specimens and the measurement of hydrogen content are based on the "Hydrogen Test" specified in "Tentative Specifications for Mild Steel Arc-Welding Electrodes" (ASTM Designation: A 233 – 48 T),[3] but with the following modifications.

Using a steel electrode of $^1/_{16}$ in. diam, a straight bead was deposited on each mild-steel plate: $^1/_4$ x 1 x 5 in., by the CO_2-O_2 arc-welding process. Four such specimens were prepared under the following conditions:

Arc voltage: 30–33 v
Welding current: 400–420 amp
Traveling rate: 16 ipm

Similar specimens were prepared by the manual arc-welding processes with covered electrodes, of which the core is about $^5/_{16}$ in. (5 mm) diam., and adopting the following conditions:

Arc voltage: 22–27 v
Welding current: 200–230 amp
Traveling rate: 6–7 ipm

Table 3—Mechanical Properties, Frequencies of Fisheye Occurrence and Hydrogen Contents of Welds by Various Welding Processes

Welding process	Electrode	Welding procedure*	Mechanical properties: Ultimate tensile strength, kg/mm² Range	Ultimate tensile strength, kg/mm² Mean	Elongation, % Range	Elongation, % Mean	Reduction of area, % Range	Reduction of area, % Mean	Frequency of fisheye occurrence: Per cent † Fisheye	Per cent † Fisheye-like	Per group Fisheye	Per group Fisheye-like	Per group Total	Hydrogen content of weld evolved in glycerin, ml/100 g Range	Hydrogen content of weld evolved in glycerin, ml/100 g Mean	Note
CO_2-O_2 arc welding	X	JIS	51–54	53	25–33	29	62–68	65	0/20	0/20	1/40	1/40	2/40 = 5%	0.06–0.27	0.15	Rubber sundust was used
		Continuous	45–53	49	27–35	32	57–70	65	1/20	1/20						
Manual-arc welding with covered electrode	Low-hydrogen type A	JIS	49–54	51	30–36	32	68–76	72	2/10	2/10	2/20	3/20		1.8–4.1		
		Continuous	47–50	48	33–37	35	71–74	72	0/10	1/10			19/80 = 24%			
	B	JIS	48–51	50	29–35	31	68–74	71	1/10	0/10	3/20	0/20		1.4–3.1	2.0	3.6 Electrode was used after drying for 1 hr at 300° C
		Continuous	44–48	46	32–36	34	63–75	72	2/10	0/10						
	C	JIS	53–55	54	29–33	31	63–74	70	1/10	1/10	5/20	2/20		3.6–7.0	4.8	
		Continuous	47–54	51	25–35	32	39–74	67	2/10	1/10						
	D	JIS	51–53	52	28–34	32	53–71	67	1/10	0/10	4/20	2/20		3.9–5.2	4.5	
		Continuous	46–52	50	30–36	32	62–70	67	1/10	2/10						
	Ilmenite-type	JIS	42–45	44	16–32	26	28–62	41	10/10	0/10	19/20	0/20	19/20 = 95%	21.3–22.9	21.9	Electrode was used as-received
		Continuous	40–44	42	22–40	32	34–66	55	9/10	0/10						

* JIS: After each pass welding and cooling for 5 min, the specimen was dipped into water of 100° C for 5 min. Continuous: The specimen was welded continuously and cooled in the air.

† "Fisheye-like" is a very little orifice in the fractured surface which has little effect on the mechanical properties of weld metal. It also looks silvery like fisheye.

Table 4—Effects of Various Conditions on Mechanical Properties, Frequency of Fisheye Occurrence and Hydrogen Content of Weld Metal Deposited by CO_2–O_2 Arc-Welding Process

Condition	Mechanical properties: Ultimate tensile strength, kg/mm² Range	Mean	Elongation, % Range	Mean	Reduction of area, % Range	Mean	Frequency of fisheye occurrence: Fisheye	Tailed	Total	Hydrogen content of weld evolved ml/100 g in glycerin, — Range	Mean
Electrode with a little of rust and rubber conduit were used	42–50	45	28–35	32	54–67	64	0.19	5.19	5.19 = 27%	0.3–0.8	0.64
Rubber conduit was used	45–53	49	27–35	32	57–70	65	1.20	1.20	2.20 = 10%	0.06–0.27	0.15
Dried gas and dried conduit were used	46–52	50	28–36	32	65–72	67	0.18	1.18	1.18 = 5.5%	0.00–0.05	<0.05

Each of these deposited specimens was immersed in glycerin for a period of 48 hr at 45° C, and the hydrogen evolved was measured by the burette of collecting apparatus, the latter being especially built thin and graduated from 0.01 to 3.00 ml for measuring the small amount of gas evolved.

Comparison of Hydrogen Contents Obtained in Different Cases

According to the data in Table 3, the hydrogen content of a weld deposited by the CO_2–O_2 arc-welding process is about 0.15 ml/100 g, much lower than by a low-hydrogen type electrode: 3.6 ml/100 g, and by an ilmenite-type electrode: 21.9 ml/100 g.

The authors had previously measured the hydrogen content of welds obtained by other welding processes and had published the results.[3] According to the literature, the following data are known:

For submerged-arc welding: 2.7 ml/100 g.

For argon-shielded metal-arc welding: 0.7 ml/100 g.

Compared with these figures, the hydrogen content of welds deposited by the CO_2–O_2 arc-welding process is very low.

Relation Between Hydrogen Content and Frequency of Fisheye Occurrence

Comparing hydrogen contents with frequencies of fisheye occurrence in Table 3, it is concluded that the latter increases with the former.

Various Factors Giving Effects on the Hydrogen Content and Fisheye Occurrence

The metal electrode used in the CO_2–O_2 arc-welding process has no flux on either the outside or the inside. Also no granulated flux covers the welding arc. That is, flux is never used in any form. The flux used in arc welding has, more or less, moisture in ordinary circumstances. And this is deemed to be a main origin of the hydrogen contained in the weld. By contrast, this process furnishes no source of hydrogen to be entrapped in the weld excepting the moisture in the atmosphere, provided that proper attention is paid to use an electrode in dried condition and to supply a gaseous mixture without moisture and hydrogen for shielding.

This point is considered to be the most important reason for the very low hydrogen content and low frequency of fisheye occurrence.

Therefore, it is vital to observe the following requirements:

1. To supply a gaseous mixture containing as small an amount of moisture as possible.
2. To cut off from the effects of the moisture in the atmosphere.
3. To use an electrode in dried and rust-free condition.

Attention to the Passage of Supplied Gas

In CO_2–O_2 arc welding, it is difficult for the moisture of the atmosphere surrounding the arc and molten pool to have a direct effect on the hydrogen content of the weld, if a sufficient and suitable flow of the supplied gaseous mixture is maintained. However, if the passages of supplied gases, such as nozzle, conduit and reducing valve, are exposed to the atmosphere containing moisture before the start of welding and some amount of moisture is adsorbed on the inside of these passages, the hydrogen content of the weld obtained by shielding with the gases supplied through such passages will suffer an indirect effect of atmospheric moisture.

In Table 4, the hydrogen content of the weld metal is below 0.05 ml for 100 g of weld where a dried conduit is used, which is less than that experienced

Table 5—Dew Point of Carbon Dioxide and Hydrogen Content of Weld

Mark	Carbon dioxide: JIS Grade*	Dew point, °C	Moisture, weight-%	Hydrogen content of weld evolved in glycerin,† ml/100 g	Frequency of fisheye occurrence in fractured surfaces of tension specimens
A		−0.5		4.23	4/4
B		−2.8		8.36	4/4
C		−5		0.04	0/4
D	1	−16	0.082	0.03	0/4
E	2	−30	0.027	0.03	0/4
F	3	−47	0.005	0.03	0/4

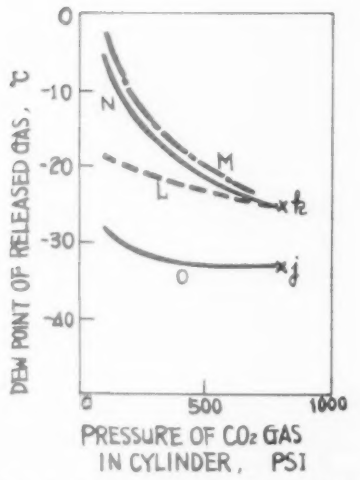


Fig. 5 Relations between dew points of released carbon-dioxide gas and pressures of residual gases in cylinders purchased commercially and in one cylinder to which there was added intentionally one liter of water

Curve L, M or O: relation concerning the cylinder containing gaseous phase of CO_2 only, purchased commercially. Curve N: Relation concerning the cylinder into which 24 kg of liquid CO_2 was charged after pouring of 1 kg of water. Volume of cylinder = 40 l. Point k or j: Relation concerning the cylinder containing CO_2 gaseous and liquid phases, purchased commercially

* According to the Japanese Industrial Standard: JIS (K 1106), the maximum permissible moisture contents for the three grades of CO_2 are as follows: Grade 1, not prescribed; Grade 2, 0.05 weight-%; Grade 3, 0.005 weight-%.

† Mean of three data.

when a rubber conduit is employed without drying: about 0.15 ml/100 g. It is considered that these data explain the circumstances mentioned above.

For this reason, it is desirable to use a dried conduit and to cover the nozzle, during the resting periods of operation, in order to shield it from the circulating moist atmosphere, particularly in a humid country like Japan.

Attention to Surface of Electrode

When using a rusty electrode, the hydrogen content of the weld metal has a tendency to show a somewhat higher value. The rust on the electrode is assumed to absorb or adsorp moisture. According to the results in Table 4, the figure obtained by an electrode with a little rust is about 0.64 ml/100 g, which is larger than the one for an electrode without rust, about 0.15 ml/100 g. Therefore, it is important to use a rust-free electrode and to hold it in a dry place.

Attention to Gaseous Mixture to Be Supplied

The effect of moisture in the carbon dioxide supplied for shielding on the hydrogen content of the weld was clarified previously by the authors.[3] Table 5 shows the applying relationship. According to these data, it is necessary to supply a gas having as small an amount of moisture as possible, namely a dew point as low as possible, for obtaining a weld with a low-hydrogen content.

In this process, a mixed gas composed of CO_2 and O_2 is supplied. Hence, an oxygen gas with a low dew point is also desirable for this purpose.

The results of experiments are described hereafter.

Measuring Method of Dew Point

During the release of gas from a cylinder containing compressed gas or compressed gas and liquid, the dew points of the released gas were measured momentarily with a photocell-type dew-point meter[4] which was connected by means of a short glass tube with the reducing valve set to the cylinder.

Dew Point of Carbon Dioxide in the Market

Two cylinders, L and M, containing gaseous and liquid carbon dioxide were furnished from two different factories.

While liquid and carbon dioxide gas coexist in the cylinder, there is no change in the pressure of the gas in the cylinder during the release of the gas and no change in the dew point of released gas, if the releasing rate is not extremely rapid. In Fig. 5, the point k indicates the pressure and dew point in such condition.

If the release of the gas continues until only the gaseous phase of the content is left, the pressure of the gas in the cylinder begins to fall with the release. And the dew point of the released gas rises with the fall of the pressure. The curves L and M denote these tendencies. The curve L is almost linear and M is a curve approximating the exponential function.

A carbon dioxide gas showing the tendency of M is not recommendable as the supplied gas for obtaining weld metal having a low content of hydrogen.

From the cylinder containing gaseous and liquid carbon dioxide with water added thereto (weight ratio of water/carbon dioxide, 1:24), the Curve N was obtained by releasing the gas.

Based on this, it is surmised that the carbon dioxide M also must have some amount of separated water.

To obtain a weld metal having as small an amount of hydrogen as possible, it is preferred to use gas released from a cylinder in which both liquid and gaseous carbon dioxide coexist. A gaseous carbon dioxide showing the tendency of M or N should not be used down to a low pressure for shielding purposes. But a gaseous carbon dioxide showing the tendency of Curve L can be utilized down to low pressure, though this is not desirable. For obtaining a very low hydrogen content in the weld metal, it is recommended to use the carbon dioxide having a low dew point such as j. Such gas can be used until low pressure is reached.

Dew Point of Oxygen in the Market

In the cylinder containing oxygen, there is nothing but oxygen gas. The authors' experiments reveal that the dew point of the released oxygen rises with a decrease in the pressure of the gas in the cylinder. In Fig. 6, Curves P, R and S show such tendencies of three kinds of oxygen furnished. Also, Curve Q shows the trend of the oxygen released from a cylinder containing both oxygen and separated water. In this case, 4000 l of oxygen was compressed and charged after pouring 1 l of water in the cylinder of 30 l in volume. Accordingly, oxygen such as S or R is also supposed to have separated water. The dew points of these oxygen gases are higher than that of oxygen (P) free of separated water under all pressures.

It is desirable to use the oxygen designated as P as a gas additive to the carbon dioxide.

Pressure of Gas in Cylinder and Hydrogen Content of Weld

The gas released from the cylinder containing liquid and gaseous carbon dioxide was supplied as the main gas for shielding. The released gas registered the constant dew point of −33° C and this condition is represented by the point j in Fig. 5. Oxygen gases P and Q shown in Fig. 6 were added separately to the carbon dioxide gas j mentioned above.

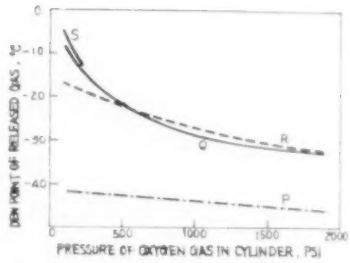


Fig. 6 Relations between dew points of released oxygen and pressures of residual gases in the cylinders which were obtained commercially and in the cylinder to which 1 l of water was added intentionally

Curve P, R or S: relation concerning the cylinder available commercially. Curve Q: Relation concerning the cylinder into which 4000 l of O_2 gas was compressed and charged after adding of 1 l of water. Volume of cylinder = 30 l

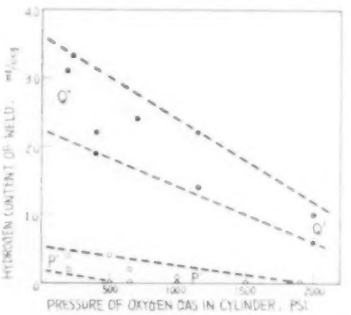


Fig. 7 Hydrogen content of weld deposited by CO_2-O_2 arc-welding process, supplying the mixture of CO_2 and O_2 released at various pressures of the cylinder

●—In released gas from the cylinder (Q in Fig. 6) into which 4000 l of O_2 gas was compressed and charged after pouring of 1 l of water. ○—In released gas from the cylinder (P in Fig. 6) into which O_2 gas was compressed and charged after drying the cylinder. The dew point of released CO_2 gas was −33° C

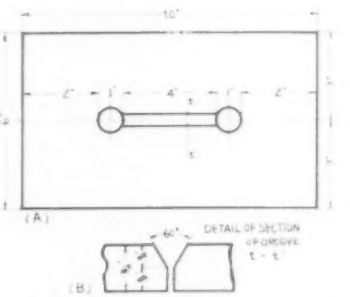


Fig. 8 Specimens for the I-shape crack test

Groove was welded in one pass at room temperature, 15° C

Using such mixed gases, weld metals were deposited and the hydrogen contents were measured by the same method as shown before. Figure 7 shows these results. With the fall of pressure of oxygen in the cylinder, the hydrogen content of the weld deposited with the shielding of the gas released from the cylinder, increases as shown with the tendency *Q'Q"* by the Oxygen *Q* or with the one *P'P"* by the Oxygen *P*. But the hydrogen contents representing the tendency *P'P"* are much lower than those representing *Q'Q"*. This fact is presumed to be due to the difference between dew points in both cases. The same observation is also made on the carbon dioxide.

Selection of Gases to Be Supplied

To obtain a weld metal having low-hydrogen content, it is essential to supply a gas mixture of carbon dioxide and oxygen containing as little moisture (and hydrogen) as possible.

Therefore, the carbon-dioxide gas, released from a cylinder containing liquid and gaseous carbon dioxide or a cylinder containing only gas, having a lower dew point as shown by the point *J* or the Curve *O* in Fig. 5 and the oxygen gas having a lower dew point as shown by the Curve *P* in Fig. 6, are suitable as the gases supplied for the shielding of the arc and molten pool.

Table 6—Bead-Crack Tests on I-Shape Specimens

Process	Procedure	Diam. of electrode, in.	Percentage of crack* — Bead crack	Percentage of crack* — Crater crack	Frequency of crack occurrence — Bead crack	Frequency of crack occurrence — Crater crack	Note
CO_2-O_2 arc welding†	Manual	5/32	0	14			
			0	18			
			0	10			
			0	17			
			0	30	0/9 = 0%	9/9 = 100%	Without crater treatment
			0	16			
	Automatic	1/8	0	39			
			0	38			
			0	18			
			0	0			
			0	0			
			0	0			
	Manual	5/32	0	15	0/7 = 0%	1/7 = 14%	With crater treatment
			0	0			
			0	0			
			0	0			
			0‡	0			
Arc welding with low-hydrogen-type electrode	Manual	5/32	0‡	6	0/4 = 0%	1/7 = 14%	Electrodes were used after drying for 1 hr at 300°C
			0‡	13			
			0	0			
			0‡	0			
			0‡	0			
		3/16	0‡	0			
Inert-gas-shielded metal-arc welding	Manual	5/32	100	100	3/3 = 100%	5/5 = 100%	Shielding gas, Ar + 5% O_2
			100	100			
			100	100			
	Automatic	5/32	0	16			
			0	8			
Submerged-arc welding	Automatic	5/32	100	100	2/3 = 67%	3/3 = 100%	
			100	100			
			0	13			
Arc welding with ilmenite-type electrode	Manual	5/32	100	100	7/7 = 100%	7/7 = 100%	Electrodes were used as-received
			100	100			
			100	100			
			100	100			
			100	100			
		3/16	95	100			

* Percentage of bead crack = $\frac{\text{Length of crack in bead except crater}}{\text{Length of bead except crater}}$

Percentage of crater crack = $\frac{\text{Length of crack in crater}}{\text{Length of crater}}$

† In this experiment, CO_2 gas of 2nd grade specified by JIS, and O_2 gas in market were used.

‡ Longitudinally broken surface of bead showed a colored part in a root, which seemed to be hot crack.

Crack Sensitivity

Various crack tests were carried out on welded joints made by the CO_2-O_2 arc-welding process. The welded joints made by other arc-welding processes were also subjected to the same crack tests.

Bead Crack Tests on the I-Shape Specimens

The I-shape crack test specimen has been used previously for alloy steels.[7] The similar type of specimen was adopted in the test of this paragraph.

In the central part of a high-tensile steel plate, 3/4 x 10 x 6 in., two holes were bored as shown in Fig. 8 (*A*) and a groove was cut as shown in Fig. 8 (*B*). The results of chemical analysis (%) of the steel were as follows:

C	0.18
Si	0.48
Mn	1.51
P	0.023
S	0.017
Cu	0.14
Ni	0.02
Cr	0.05
Al	0.055

Such base plates were prepared in large numbers. Then the groove in

(A) By manual CO_2-O_2 arc welding

(B) By manual-arc welding with low-hydrogen-type electrode

(C) By manual inert-gas-shielded metal-arc welding

(D) By automatic submerged-arc welding

(E) By manual-arc welding with ilmenite-type electrode.

Fig. 9 Photos showing the results of the dye-penetrant inspection of I-shape crack specimens

each base plate was welded in one pass by various processes. In so doing, the best conditions of welding were selected for each process to weld such a joint. When a week elapsed after welding, the existence or nonexistence of bead crack on all specimens was investigated by means of the dye-penetrant and radiographic-inspection methods; then, the cross sections of weld beads were examined with the microscope, but only for the specimens in which no crack had been detected in the above inspections. These experimental results are enumerated in Table 6 with various notes concerning procedure, electrodes used and other factors.

In this table, the percentage of cracks occurring in the weld beads is indicated by the ratio of length of crack to length of bead. Such percentage is also taken on crater cracks. The frequency of crack occurrence is expressed by the ratio of the number of cracked specimens to the number of total specimens examined for each welding process. Examples of bead appearance examined by the dye penetrant are given in Fig. 9, and the longitudinal crack is recognized in each of (*C*), (*D*) and (*E*) of these photographs. According to these results, the frequency of bead-crack occurrence becomes greater in the following order:

1. CO_2-O_2 arc welding.*
2. Manual-arc welding with low-hydrogen-type electrodes.
3. Inert-gas-shielded metal-arc welding.
4. Submerged-arc welding.
5. Manual-arc welding with ilmenite-type electrode.†

* Lowest.
† Highest.

As for the frequency of crater-crack occurrence, any automatic welding without crater treatment shows a high value. But this tends to be decreased through adoption of an adequate crater treatment with which a deep crater is filled with deposited metal and the surface of the part becomes flat. For example, while the frequency of crater-crack occurrence is 9/9 in the case of the CO_2-O_2 arc-welding process without crater treatment, it is 1/7 in the case of the process with crater treatment. That is, crater cracks may be prevented through suitable crater treatment.

According to the results enumerated in Table 3, the hydrogen content of weld metal becomes higher in the following order:

(*a*) CO_2-O_2 arc welding: 0.15 ml/100 g.*
(*b*) Manual-arc welding with low-hydrogen-type electrode: 3.6 ml/100 g.
(*c*) Manual-arc welding with ilmenite-type electrode: 21.9 ml/100 g.†

According to the reference,[7] the hydrogen content of weld deposited by the inert-gas-shielded metal-arc process is about 0.7 ml/100 g, and the value by submerged-arc welding is about 2.7 ml/100 g. Therefore, it is considered that the percentage or the frequency of bead crack increases with an increase in the hydrogen content of the weld.

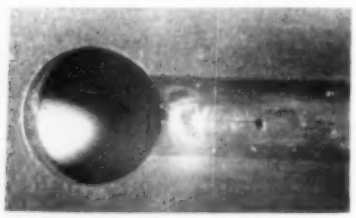
In the case of the CO_2-O_2 arc-welding process, the hydrogen content of the weld is very low and the percentage and the frequency of bead crack are smaller than for other processes. Furthermore, the percentage or the frequency of crater crack, obtained by the CO_2-O_2 arc-welding process, is very small, if a suitable crater treatment is applied. Figure 10 (*A*) shows defects occurring in a crater and this kind of crack is prevented as shown in Fig. 10 (*B*) through adoption of crater treatment.

Bead-Crack Tests on the Y-Slit RTRI Specimens

In Japan, the y-slit crack test is adopted occasionally, after the Railway Technical Research Institute (RTRI) method,[8] for the examination of a covered electrode to estimate the crack sensitivity of weld metal obtained with such an electrode.

This type of bead-crack test was also tried in this research. The base plate used was a high-tensile steel having the same chemical analysis as the I-shape specimen. The form and size of the base plate and grooves are illustrated in Fig. 11. The two grooves of base plate were filled in by semiautomatic CO_2-O_2 arc welding or by manual-arc welding with covered electrodes. When a week elapsed after deposition, existence or nonexistence of the bead cracks was first checked with the dye-penetrant and the radiographic-inspection methods, and then the cross sections of the beads were investigated with the microscope, on all specimens. Table 7 lists these experimental results.

According to the results, the percentage and the frequency of bead crack obtained by the CO_2-O_2 arc-welding process are smaller than by the manual-arc-welding processes with covered electrodes. This is shown in Fig. 12. For example, in the cases of manual-arc welding with covered electrodes, one or two large cracks are recognized by observing the bead surfaces and the



(A) Without crater treatment

(B) With crater treatment

Fig. 10 Effect of crater treatment on the crater crack in case of CO_2-O_2 arc welding

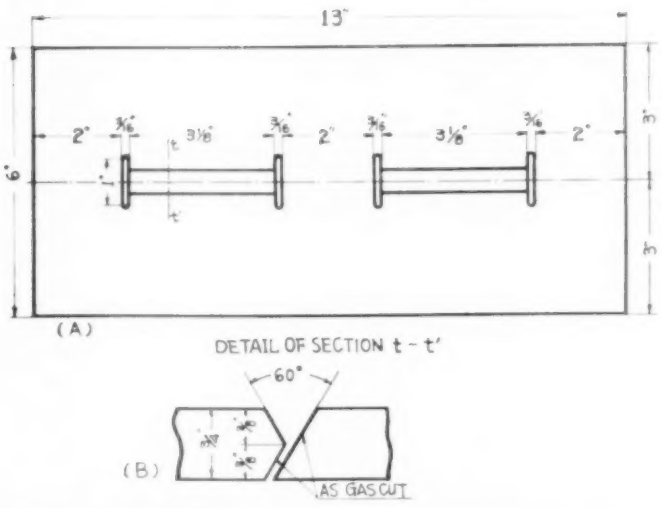
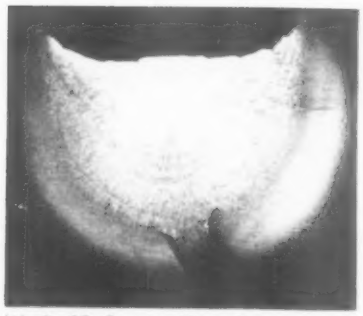
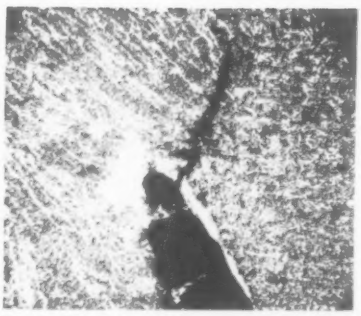


Fig. 11 The y-slit RTRI specimen

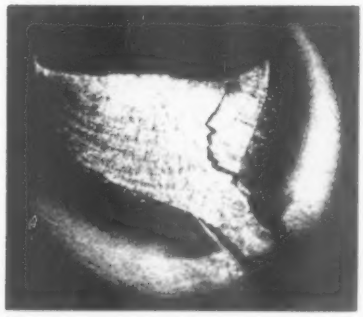
(A) Right groove was welded immediately after welding of left groove. Each was welded in one pass.
(B) Start and crater of bead were outside groove. The welding of specimen was carried out at room temperature, 15° C.



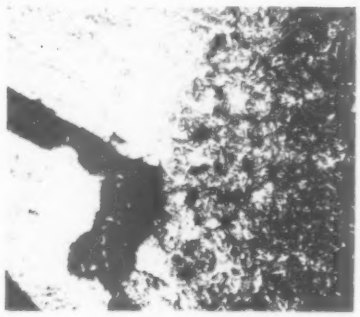
(A) By CO_2–O_2 arc welding. X 4



(B) By CO_2–O_2 arc welding. X 75

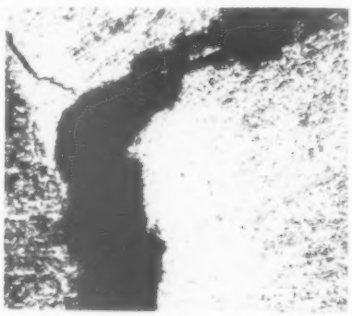


(C) By manual-arc welding with low-hydrogen-type electrode. X 4



(D) By manual-arc welding with low-hydrogen-type electrode. X 75

(E) By manual-arc welding with ilmenite-type electrode. X 4



(F) By manual-arc welding with ilmenite-type electrode. X 75

Fig. 12 Macro- and microphotos of cross section of bead deposited in the groove of the y-slit RTRI specimen

Table 7—Bead Crack Tests on y-Slit RTRI Specimens*

Process	Procedure	Electrode — Type	Electrode — Diam., in.	Percentage of bead crack†	Frequency of bead-crack occurrence	Note
CO_2–O_2 arc welding	Manual	X	1/16	0	0/2‡	Without crater treatment
			5/32	0		
Arc welding with covered electrode	Manual	Low hydrogen	1/16	100	4/4	Electrodes were used after drying for 1 hr at 300° C
			5/32	100		
			3/16	55		
			7/32	100		
	Manual	Ilmenite	1/16	100	4/4	Electrodes were used as-received
			5/32	100		
			3/16	100		
			7/32	97		

* The bead-crack test specimen adopted occasionally in Japan.

† Percentage of bead crack = $\frac{\text{length of crack}}{\text{length of bead}}$.

‡ A root crack was slightly recognized on the cross section of welds.

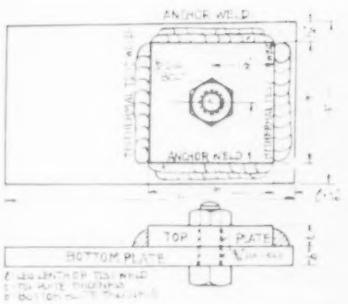


Fig. 13 The CTS weldability assemblies (quoted from C. L. M. Cottrell)

cross sections of the weld beads. However, on beads deposited by CO_2–O_2 arc welding, there is no crack discernible on the surface of the bead and a slight crack can be seen only at the root of the weld.

Underbead Crack Appearing in the CTS Weldability Test

The CTS weldability test assembly,[8] as seen in Fig. 13, was adopted for observation of underbead cracks. Table 8 shows the chemical analyses (%) of high-tensile low-alloy steel plates used for this experiment. The thickness for top and bottom plates and thermal severity numbers (TSN) in this test are noted in the remarks of Table 9 for each kind of steel. When a week passed after welding, the bithermal and trithermal test welds were cut off into four pieces by three cross sections, and the three sections of each weld were observed under the microscope, according to the procedure of Cottrell.[8] The results are shown in Table 9. According to this table, underbead cracks develop in case of the manual-arc welding with an ilmenite-type electrode and seldom with a low-hydrogen-type electrode, but never with CO_2–O_2 or inert-gas-shielded metal-arc welding.

Various Cracks in the Vicinity of Bead

Many rectangular steel plates, having the sizes listed below, were prepared and one straight bead was deposited on the central part of each plate by each of the various available welding processes: 1/4 x 3 1/8 x 3 1/8 in., 19/32 x 3 1/8 x 3 1/8 in. The chemical analysis (%) of the low-alloy steel plate is as follows:

C	0.45
Si	0.25
Mn	0.47
Ni	2.80
Cr	1.23
Mo	0.27
P	0.016
S	0.007
Cu	0.10

The cross section, perpendicular to the bead, of the square specimen was made by cutting with a grinding wheel of small thickness. In this case, the tem-

Table 8—Chemical Analyses (%) of High-Tensile Low-Alloy Steels for CTS Weldability Test

Test mark of steel*	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	B	Al	Note
A	0.10	0.36	1.52	0.017	0.007	0.16	0.05	0.11				0.02	As-rolled
B	0.15	0.22	0.71	0.014	0.010	0.22	0.84	0.50	0.51	0.065	0.003		Water quenched after heating for 30 min at 930° C and water cooled after heating for 60 min at 650° C

* Ultimate tensile strength, kg/mm²: 53 for Steel A, 95 for Steel B.

Table 9—CTS Weldability Tests

Process	Kind of steel plate*†	Frequency of underbead crack occurrence‡ Bithermal	Trithermal
CO_2-O_2 arc welding	A	0/12	0/12
	B	0/3	0/3
Inert-gas-shielded metal-arc welding	A	0/12	0/12
	B		
Manual-arc welding with low-hydrogen-type electrode	A	0/12	0/12
	B	1/3	0/3
Manual-arc welding with ilmenite-type electrode	A	1/6	3/6
	B	1/3	2/3

* Thickness of top (T) and bottom (B) plates: 3/8 in. for Steel A, 25/32 in. for Steel B.

† Thermal severity number:

For bithermal welds	For trithermal welds	
4T + B = 7	4T + 2B = 10.5	(for Steel A)
4T + B = 6.3	4T + 2B = 9.4	(for Steel B)

‡ The denominator indicates the number of sections observed, i.e., the number of specimens × 3; the numerator, the number of sections on which the underbead crack was recognized microscopically.

perature rise was prevented by cooling with a cold-water jet to avert the change of microstructure in the bead and in its surrounding area.

In the same manner, the longitudinal section through the centerline of the bead was also prepared. Then these surfaces were polished and etched with 5% nital. Existence or nonexistence of various kinds of crack in the affected zone by welding was investigated.

It has already been clarified that various cracks appear in welded specimens consisting of low-alloy steel, and that these cracks can be classified into four types:[20] (1) underbead crack; (2) toe crack; (3) transverse crack; and (4) longitudinal crack. The typical positions of such types of cracks are shown in Fig. 14, with the results of the investigation enumerated in Table 10.

From these results, the following points are deduced:

1. The underbead crack is sometimes recognized in a specimen made by manual-arc welding with an ilmenite-type electrode. But this type of crack does not occur in a specimen made by the manual-arc welding with a low-hydrogen-type electrode, the inert-gas-shielded metal-arc welding or the CO_2-O_2 arc welding. This is supposed to be due to the difference in the hydrogen content of the weld since that content of weld by the former process is extremely greater than by any of the latter.

2. Transverse cracks are less likely to occur in the specimens whose hydrogen contents have a tendency to show a smaller value and which are welded by processes such as inert-gas-shielded metal-arc welding or CO_2-O_2 arc welding.

3. Toe cracks occurred in specimens welded with all welding processes. Lon-

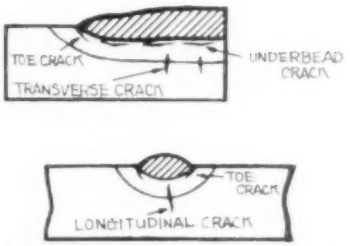


Fig. 14 Various cracks in the neighborhood of bead (these were classified by Sekiguchi & Kobayashi[20])

Table 10—Various Cracks in the Neighborhood of Bead Deposited on Ni-Cr-Mo Steel Plate

Process	Electrode	Kind and flow of shielding gas	Thickness of specimen	Underbead crack: Occurrence	Underbead crack: Frequency	Underbead crack: Total frequency	Toe crack: Occurrence	Toe crack: Frequency	Toe crack: Total frequency	Transverse crack: Occurrence	Transverse crack: Frequency	Transverse crack: Total frequency	Longitudinal crack: Occurrence	Longitudinal crack: Frequency	Longitudinal crack: Total frequency
CO_2-O_2 arc welding	X	CO_2, 29 cfh O_2, 11 cfh	15	No	0/2	0/4	No	1/2	3/4	No	0/2	0/4	No	0/2	0/4
				No			Yes			No			No		
			6	No	0/2		Yes	2/2		No	0/2		No	0/2	
				No			Yes			No			No		
Inert-gas-shielded metal-arc welding	X	A, 50 cfh O_2, 3 cfh	15	No	0/2	0/4	No	1/2	3/4	No	0/2	0/4	No	0/2	0/4
				No			Yes			No			No		
			6	No	0/2		Yes	2/2		No	0/2		No	0/2	
				No			Yes			No			No		
Arc welding with covered electrode	Low-hydrogen type		15	No	0/2	0/4	No	1/2	3/4	No	1/2	1/4	No	0/2	0/4
				No			Yes			Yes			No		
			6	No	0/2		Yes	2/2		No	0/2		No	0/2	
				No			Yes			No			No		
	Ilmenite type		15	Yes	2/2	2/4	No	0/2	2/4	No	1/2	1/4	No	0/2	0/4
				Yes			No			Yes			No		
			6	No	0/2		Yes	2/2		No	0/2		No	0/2	
				No			Yes			No			No		

gitudinal cracks were not observed in any specimen made by various welding processes. Therefore, these two cracks are regarded to have no direct relation to the magnitude of hydrogen content of weld.

These observations are not inconsistent with the conclusion of a paper[9] published earlier.

Bead-Crack Tests for Steels Containing Sulfur

Bead-crack tests were carried out for the various welding processes with a free-cutting steel having the following analysis (%):

C	0.12
Si	0.16
Mn	0.60
P	0.010
S	0.134
Cu	0.21
Ni	0.12
Cr	0.10

In this case, a tee joint having a fillet weld on one side was made as shown in Fig. 15.

When a week elapsed after welding, two notches were cut at both ends of each fillet, and each test bead was broken by external blows. Then, the fractured surface of each test bead was examined with the naked eye for existence or nonexistence of colored areas. The assumption was made that it was at the colored areas in the fractures that hot cracks occurred. The results are given in Table 11.

According to this, hot cracks developed in cases of manual-arc welding with a low-hydrogen-type electrode and an ilmenite-type electrode. In case of the latter-type electrode, many pits appeared on the resulting bead surface. Hot cracks did not occur in the cases

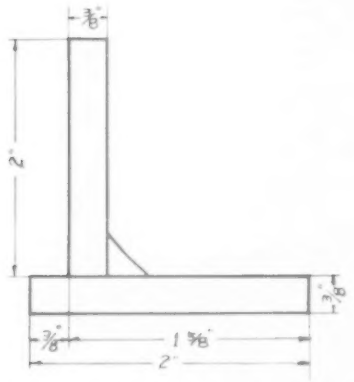


Fig. 15 Tee joint for bead-crack test of free-cutting steel (length of joint: 6 in.)

of CO_2-O_2 arc welding and inert-gas-shielded metal-arc welding.

A straight bead was deposited on the longitudinal groove, 45 deg and $\frac{1}{4}$ in. in depth, made on centerline of rectangular plate of the above-mentioned steel, measuring $\frac{3}{4}$ x 12 x 4 in. After the deposition, radiographs were taken on the central part of this bead and existence or nonexistence of bead cracks and blowholes was investigated. The results are also included in Table 11. From these data, it is apparent that when CO_2-O_2 arc welding is used, beads which scarcely contain defects can be obtained on a free-cutting steel, too. However, with CO_2-O_2 arc welding, as well as with other processes, it would be inevitable to some extent to have a crack at the toe or at the crater of the bead. Some preventive measures must be devised for such defects.

Table 11—Cracks and Blowholes Appeared in Weld Metal on Free-Cutting Steel

	Occurrence of hot crack by tee joint test	*Radiographic examination of bead* — *Bead crack* — *Number*	*Total length, mm*	*Number of blowhole* — *Slag*	*Center*	*Crater*	*Note*
Process							
CO_2-O_2 arc welding	No	0	0	0	10	6	Appearance good
Inert-gas-shielded metal-arc welding	No	0	0	4	29	8	Appearance good
Submerged-arc welding	Yes	3	7	0	24	5	Appearance good
Manual-arc welding with low-hydrogen-type electrode	Yes	4	25	80	16	6	Vigorously spattering
Manual-arc welding with ilmenite-type electrode	Yes	13	57	17	63	11	Many pits on the surface of bead

Summary

In this report, the authors have given, first of all, an outline of the CO_2-O_2 arc-welding process. Next, they have discussed the frequency of fisheye occurrence, hydrogen content and crack sensitivity as measured on welds prepared by the various welding processes. These results are summarized as follows:

1. In the CO_2-O_2 arc welding of mild steel with consumable steel electrode containing sufficient and suitable quantities of deoxidizers, the hydrogen content of the weld is much lower, and the frequency of fisheye occurrence is smaller, than for the other welding processes. According to the experimental results obtained with high-tensile low-alloy steels, the CO_2-O_2 arc-welding process showed the smallest frequency of crack occurrence in the weld.

2. As may be seen from the results obtained in the CTS weldability tests on high-tensile low-alloy steels welded by the various processes, the CO_2-O_2 arc-welding process as well as the inert-gas-shielded metal-arc-welding process showed a lesser tendency toward underbead cracking than the manual-arc-welding process with a covered electrode.

3. The results of crack tests on a free-cutting steel containing sulfur showed that hot cracks and blowholes are less likely to occur both in the bead deposited by the CO_2-O_2 arc welding and in the one by the inert-gas-shielded metal-arc welding process, than in beads deposited with the manual-arc welding with covered electrodes.

However, in order to secure such low content of hydrogen and low crack sensitivity of the weld by the CO_2-O_2 arc-welding process, the following precautions should be taken:

(*a*) A gaseous mixture of carbon dioxide and oxygen, which contains as small an amount of moisture as possible, must be supplied.

(*b*) The passage ways for the gaseous mixture, e.g., nozzle, conduit and reducing valve, must be kept dry.

(*c*) The use of dry and rust-free electrodes is required.

The above mentioned characteristics of the CO_2-O_2 arc-welding process, relating to the hydrogen content and crack sensitivity, are considered to be due to the fact that flux is never used, in any form, with this process, thereby avoiding the possibilities of introducing moisture.

In every welding process, crater cracking tends to occur when welding base-metal plates of high-tensile steel held in a strongly restrained condition. This tendency seems to be more pronounced in automatic welding. However, with the CO_2-O_2 arc-welding process, this type of cracking can be pre-

vented easily through proper crater treatment.

Conclusion

According to the experimental results reported herein, the CO_2-O_2 arc-welding process may be considered as an excellent process for producing welds which have very low hydrogen content and low crack sensitivity. It has been found that some precautions for reducing the moisture content of the gaseous mixture to be used with this process must be taken to attain such superiority.

A discussion of this process was given first in this report, but the details on other advantages of this process were not given. These may be found in Reference 3.

This process is applied economically for welding rimmed, semikilled and killed steels in Japan. Also, it is believed that this is one of the most sound and reliable arc-welding processes for low-alloy steels. Further, this process may be applied for free-cutting steels.

Acknowledgment

The authors were encouraged and advised by Dr. S. Nishikori in carrying out this research and hereby express their feelings of gratitude. The Daido Steel Co. Ltd., the Tone-Seiki Co. Ltd. and the Osaka Transformer Co. Ltd. were most helpful in promoting this research. The Showa Tansan Co. Ltd. and the Japan Oxygen Co. Ltd. cooperated in this work by furnishing the gases that were used. The authors wish to thank these companies for the help and cooperation extended.

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IMPROVING THE FATIGUE LIFE OF SPOT WELDS

(Continued from page 315-s)

rangement of internal stresses both in the spot weld itself and its immediate environs. In Fig. 7 this is accomplished through double compression using an outside ring and a center pin.

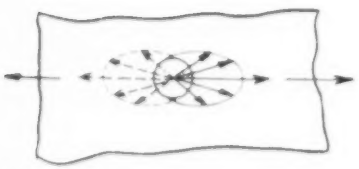

Fig. 4 Displacement of stress rosette under tensile load in a spot weld as received

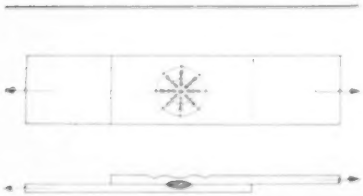

Fig. 5 Resultant residual stress in a spot weld compressed from one side only

As shown, a part of these stresses is derived inwardly in the area between the compression ring and the spot. Another part is derived within the spot from the tip compression which directs the stresses outwardly.

With sheet material the optimum relationship of these counteracting plus and minus stresses requires time consuming fatigue tests. The 10 millions of cycles limit must be approached.

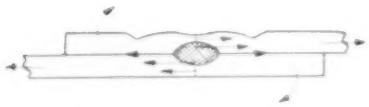

Fig. 6 Stress distribution in a spot weld (compressed from one side only) under tensile load

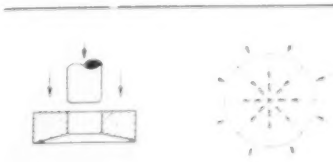

Fig. 7 Residual stresses and prestresses in a spot weld induced with tip and ring compression

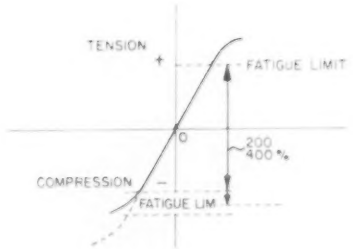

Fig. 8 A representation of fatigue resistance improvement effected by hydrostatic or hydrodynamic compression

As shown in Fig. 8, high fatigue life requires that the introduced stresses (due to an external load) start at a negative load, which should be as low as possible.

Thus, an important part of the total external load will be absorbed by these negative stresses as it starts far below the zero load.

For example—approximately half of the applied load on the spot will be absorbed by the negative internal stresses designed as compression stresses. The balance of the load will be absorbed by the positive (tension) stresses.

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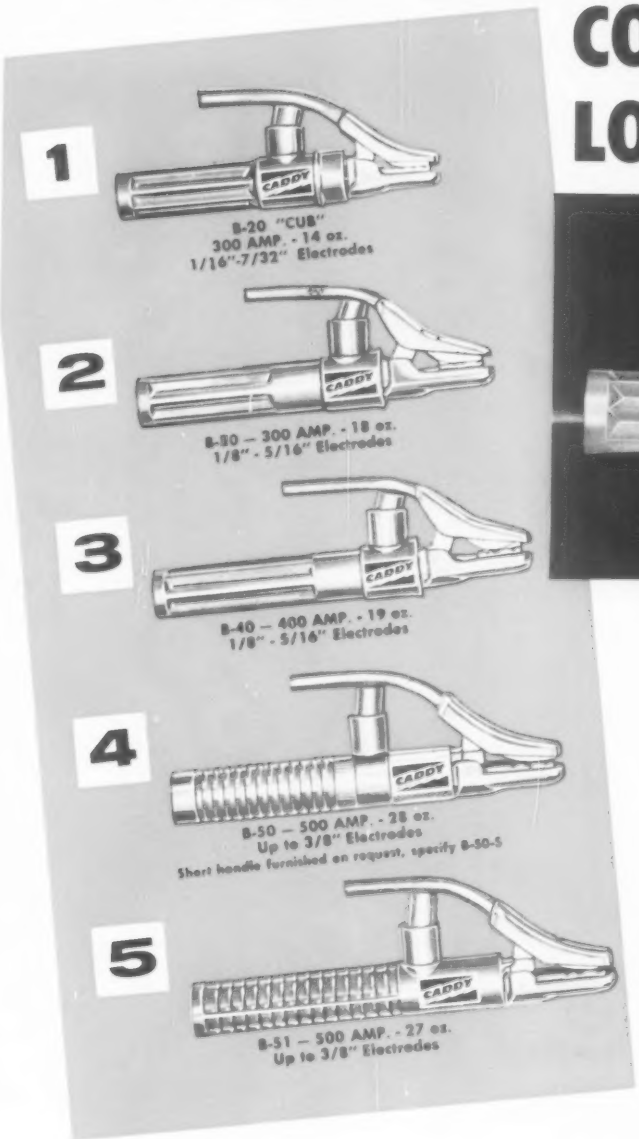

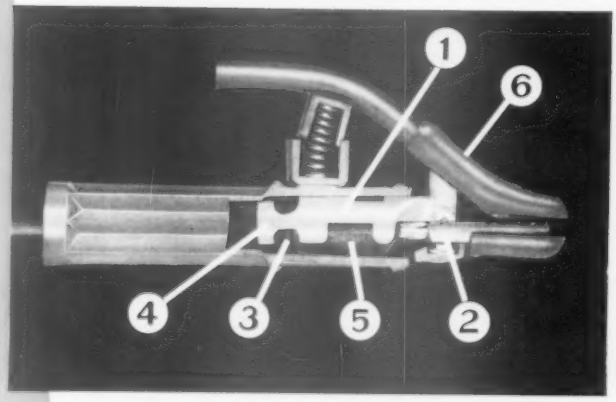

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